The built environment, walking and health inequalities in urban Scotland

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Declaration

I certify that this thesis has been composed by myself and the work is my own. This work has not been submitted for any other degree or professional qualification.

Signed:

Date:

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List of Abbreviations

AWP	Area Walking Potential
BE	Built Environment
PA	Physical activity
SES	Socioeconomic Status
SHeS	Scottish Health Survey
SMID	Scottish Index of Multiple Deprivation
ITN	Integrated Transport Network
PoI	Points of Interest

Abstract

Background: Many adults do not take recommended amounts of physical activity (PA). This is associated with adverse health outcomes such as obesity, overweight, diabetes and heart disease. Moreover, physical inactivity is socially patterned. People with lower socioeconomic status or who live in more deprived areas do less PA which may in turn contribute to inequalities in health outcomes. Identifying the causes and possible pathways for increasing PA and addressing health inequalities is a pressing national and international priority.

There is increasing evidence that features of the built environment (BE) can support physical activities such as walking. The built environment may also ameliorate health inequalities by providing a supportive context for walking across diverse sections of the population. However, there is little evidence relating to the UK and Scottish context or about inequalities in these associations for different groups such as people with different demographic characteristics or people living in areas with different levels of deprivation. This study aimed to fill this knowledge gap, examining associations between built environments and walking in urban Scotland. It considered individual and spatial inequalities in these relationships.

Methods: This study had a quantitative cross-sectional design. Geographical Information Systems (GIS) was used to create neighbourhood level BE measures of Area Walking Potential (AWP) across urban Scotland. These were destination accessibility, street connectivity, residential density and walkability (a composite measure of the former three measures).

An examination of the distribution of AWP across Scotland and in relation to area deprivation was made. The measures were then appended to individual level walking data for adults aged 19+ years from the 2010 Scottish Health Survey. Regression analysis tested for associations between the AWP measures with four different walking outcomes: any walking, frequency of walking, achieving 30 minutes of walking per day and total minutes walked in the previous week. Individual and area level confounders were controlled for. Associations were examined using two sizes of neighbourhood area: 500m and 1000m zones around residential centres. Interactions with individual demographic, socioeconomic, household characteristics and area deprivation were evaluated.

Results: There was modest evidence of positive associations between AWP and walking. After controlling for covariates, destination accessibility showed the strongest associations with frequency of walking. There were limited associations for street connectivity and walkability and no associations between residential density and walking. Positive associations remained for some groups less likely to walk, such as older adults. However, there were also interaction effects showing inequalities in associations between AWP and walking. In particular, people with lower educational attainment were less influenced by AWP. The spatial analysis showed areas with lowest deprivation had lowest AWP although people in more deprived areas walked less overall.

Conclusions: There is some evidence that the BE supports some types of walking in Scotland. The BE may also enhance walking opportunities for certain groups who generally walk less, and therefore could potentially reduce inequalities in health outcomes. However, the socioeconomic inequalities in outcomes suggest multifaceted approaches to increasing walking are more likely to reach all sections of the population. The evidence that there are geographic inequalities in levels of AWP can be used to inform geographically targeted interventions aimed at improving walking environments. This research has generated original evidence in the Scottish context, highlighting the importance of context specific research.

Lay Summary

Lack of physical activity is a pressing problem in Scotland as it is in many other countries. Not taking part in enough physical activity can lead to serious health problems such as diabetes, heart disease and obesity. People who are worse-off or who live in worse-off areas take part in less physical activity than those who are better-off. Tackling these problems is an important part of Scottish and international policy. Encouraging walking is seen as a good way of increasing physical activity because it does not cost anything and can be done by most people as part of their day-to-day life. This means it is possible that encouraging walking can help people who are worse-off or who live in worse-off areas to increase their physical activity.

People living neighbourhoods with certain features such as well-connected streets, high housing density and many destinations such as shops and schools have been found to walk more. But research has generally been carried out elsewhere, such as in the US. Not much is known about what types of neighbourhoods are good for walking in Scotland. To find out more about these issues, four measures of Scottish neighbourhoods that were considered important for walking were developed. These were well-connected streets, high housing density, many destinations and a combined measure of all three called 'walkability'. Urban neighbourhoods in Scotland were scored to show levels of each of the features. This research aimed to answer the following questions in Scotland:

- Are neighbourhoods with well-connected streets, high housing density, many destinations and high walkability spread equally throughout urban Scotland, or are there some places that have higher or lower levels?
- Do people living in neighbourhoods with well-connected streets, high housing density, many destinations and high walkability walk more? Is this the same for everyone or are there differences, for example, for different age groups, genders and for people in different types of places?

The pattern of neighbourhood scores in urban Scotland were examined to understand whether certain places had high or low levels of these neighbourhood features or whether they were distributed equally across Scotland. Neighbourhood scores were then compared with the amount of walking that residents did. The results were checked to find out whether the results were the same for different groups of people and people living in better and worse-off areas.

The results showed that people living in neighbourhoods with higher scores for some of the features walked more. In particular, people living in neighbourhoods with more destinations were more likely to walk. However, this was not the same for everyone. For example, people with lower qualifications walked less than people with higher qualifications even when they lived in places with more destinations. Worse-off neighbourhoods generally had higher scores but people living in these areas still walked less than people living in better-off neighbourhoods.

These results show that neighbourhood features such as more destinations might encourage people to walk. However, some people, might need different or additional approaches to encourage them to walk more. This research provides fresh evidence in Scotland which is different from international evidence. This shows the importance of carrying out research in different places.

Chapter 1. Introduction

1.1 Background to the research

Physical inactivity is a pressing national and international concern (The Scottish Government 2010; Department of Health 2009; NICE 2008; The Scottish Government 2014b; WHO 2010b). It poses serious health risks and is associated with increased incidence of health outcomes such as diabetes, overweight and obesity. Moreover, there is growing evidence of inequalities in physical activity behaviour, with people experiencing higher deprivation taking part in less PA (McNeill et al. 2006; Marmot 2010).

This thesis will examine these issues in Scotland. It is estimated that two thirds of Scottish adults do not take part in enough physical activity to meet current guidelines of 150 minutes moderate activity per week (Physical Activity Task Force 2003) and that this low activity contributes to around 2,500 deaths per year and costs the NHS £94 million per year (Leadbetter et al. 2014). As such, increasing physical activity and related health inequalities has been identified as a key priority in Scotland (The Scottish Government 2008). This thesis examines associations between neighbourhoods and walking, across the whole of urban Scotland. It focusses on sociospatial inequalities in the distribution of walking environments as well as inequalities for different groups of people.

This thesis contributes to this area of research by exploring pathways whereby the built environment (BE) might influence walking. Walking is a popular form of physical activity (Lamb et al. 2012; The Scottish Government 2014). Walking is considered to have the potential to increase physical activity levels across the population since it is a free form of exercise and can be incorporated as part of daily life (The Scottish Government 2014). This accessibility has led to walking being identified as a potential leveller in PA participation for groups less likely to take part in PA.

Interventions placing emphasis on individual-level determinants of physical activity, such as initiating and promoting exercise classes and personal work out regimes (Dunn et al. 1998) have met with limited success in making any substantial impact on the physical activity of populations (Lee et al. 2009). Increasingly, research is turning from a focus on the individual to the role of the environment in shaping health behaviours such as physical activity (Stokols 1996; Cavill & Rutter 2013). The specific pathways through which the environment shapes health is little understood and is likely to be a complex system of interrelated influences. One mechanism through which physical environments can influence health is through access and availability of resources in the built environment (Seaman et al. 2010) and there has been an increase in research into built environment influences on walking since the mid-2000s (Andrews et al. 2012; Bauman et al. 2012; Cummins et al. 2007; Sallis et al. 2008).

There is growing evidence of associations between measures such as access to destinations, street connectivity, residential density and walkability with walking. The concept of 'walkability' is often used as an umbrella term to describe a composite measure of features of the BE (Cutts et al. 2009). Previous research has provided evidence that these factors are associated with increased walking outcomes (Owen et al. 2004). However, ambiguity remains about associations between different features of the built environment and walking, with some evidence showing conflicting outcomes. Moreover, the majority of evidence is from the US and Australasia. There is less evidence from a European context. This is a significant gap in the literature, particularly since European urban forms, planning regimes and geographical settings are different from those in the US and Australasia (Giuliano & Narayan 2003). By providing evidence from a Scottish context, this research makes and important contribution to the international literature.

This is particularly important because research in the field of environmental health research has shown that people living in more disadvantaged areas may experience fewer health-supporting resources which may in turn contribute to inequalities in health outcomes (Shortt et al. 2014). Thus, understanding the sociospatial distribution of built environment resources that support walking, and their associations with walking behaviour, is important for understanding inequalities in walking behaviour outcomes. There is some evidence relating to inequalities in the distribution of walking environments in urban areas, but the evidence is mixed, with some showing better access in more deprived areas and other evidence showing worse access in more deprived areas, therefore making it difficult to come to conclusions about sociospatial patterns in access. Access to facilities may have a different impact on specific population subgroups who may experience and perceive their environments differently such as older adults and women, but the evidence is sparse. Research is needed to understand how built environments vary between communities, between places differing in terms of social disadvantage. By examining these issues, this thesis contributes to the national and international literature. The results are of direct consequence for policies aimed at tackling physical inactivity through developing a supportive built environment and addressing inequalities in associations between environments and physical activity.

1.2 Thesis aims

This research aims to address some of the gaps in the evidence by creating neighbourhood measures of the built environment across urban Scotland and comparing associations between these measures and the walking behaviours of residents. The research will also consider inequalities in the distribution of these measures, and in relationships between the measures and walking for people with different sociodemographic characteristics and in places with different levels of area deprivation. The thesis has four key aims:

1. To identify and create small area measures of features of the built environment considered to represent Area Walking Potential (AWP) across urban Scotland.
2. To examine the geographic distribution of the built environment measures across urban Scotland, and investigate area-level socio-spatial inequalities in access to the built environment.
3. To investigate relationships between the measures of the built environment and walking behaviour of residents in urban Scotland.
4. To identify inequalities in relationships between the built environment measures and walking for people with different sociodemographic characteristics (such as age and individual socioeconomic status) and for people living in different types of area.

1.3 Thesis outline

The first chapter of this thesis is concerned with identifying key theoretical perspectives to help inform and guide the research. It examines and evaluates socioecological models of health, physical activity and finally walking behaviours. This evaluation will be used to inform the development of a conceptual model of the potential influence of the built environment on walking to be used in this study.

This chapter is followed by a review of the international literature of associations between the built environment and physical activity and walking. This review weighs up the strength of the evidence of relationships between specific features of the BE and PA and walking. Differences in relationships between the BE and PA for certain groups of people are considered, as well as for people living in neighbourhoods with different levels of deprivation. It will consider the applicability of the findings in an urban Scottish context which will then be used to inform the selection of built environment variables to be used in this study.

Drawing on the literature reviews, the Methodology Chapter (Chapter 4) describes the quantitative methodology used to achieve the aims of the thesis. The first sections introduce the creation and development of study sites, four built environment measures of AWP and a measure of area deprivation. This is followed by a description of the analytical strategy employed for analysing the distribution of AWP measures across urban Scotland. The subsequent section describes how the AWP measures were appended to individual level data from the 2010 Scottish Health Survey and the analytical strategy for investigating relationships between the built environment and walking behaviours for residents in urban Scotland. Inequalities in relationships between different socioeconomic groups and for people living in different types of neighbourhood were considered. This is followed by two results chapters. The first examines the sociospatial distribution of the built environment measures across urban Scotland, and considers whether there are geographic inequalities in levels of AWP across urban Scotland. It analyses the distribution of AWP in relation to different types of urban Scottish neighbourhoods and in relation to area deprivation. The second results chapter investigates associations between AWP with the walking behaviour of Scottish residents. It considers inequalities in these relationships for people with different demographic, socioeconomic, household characteristics and for people living in areas with different levels of deprivation. The Discussion chapter considers the potential causes and implications of the results in relation to each of the thesis aims. The Concluding chapter (Chapter 7) considers the policy impact of the results and key strengths and contribution of the research. It summarises the limitations of the study and make recommendations for future research directions.

Chapter 2. Review of socioecological models of health, physical activity and walking

2.1. Introduction

This chapter will provide an overview of the key theoretical perspectives on which this thesis will draw, and then explain how this material will guide subsequent work. It will show that there are multiple types of influence on health, physical activity and walking that interact with individual characteristics in a complex and dynamic system. This chapter uses socioecological theory to help understand the pathways of such influences on walking. This research is based in a health geography approach, investigating contextual influences on health. Socioecological theory can be used to demonstrate many of the key facets of health geography and will be used to support this research. Andrews et al. (2012) observe that geographers use sophisticated and complex variables taking account of both the physical environment and social and interpersonal factors. A health geography perspective, incorporates the notion of complexity, being concerned with interactions between population and the environment, and how these vary across space and in different types of place (Curtis, 2004, p.22). As in socioecological models, outcomes are '*constituted, constrained* and *mediated'* (Curtis and Jones, 1998, p.651) rather than *determined* by environments and that people are active players in their dynamic interactions relationship with places. A key implication of this is that people with different characteristics such as life-stage, lifestyle and biological attributes may have different interactions with their environments. Such individual 'time-space biographies' (Cummins et al, 2007, p.1830) involve the notion that movements and exposure varies between different people, and individual characteristics influence movement activities and thus exposure to environments. As well as the physical attributes of places, a health geography perspective can view environments as socially constructed, with an awareness of the cultural importance of places (Kearns and Moon 2002). Places are considered to be imbued with meaning and significance and may be interpreted in terms of senses of place, which result from the ways that individuals and communities associate certain geographical settings with social significance and values (Curtis 2004). Health geography is concerned with inequalities in outcomes and consider that 'processes influencing individual health experience may operate differently in different places.' (Curtis and Jones, 1998, p645). For example, the aggregated socio-economic profile of populations may influence cultural dimensions of places, which in turn could influence how people behave in these places (*ibid*). Thus, people living in different areas with similar physical built environment attributes but different levels of socio-economic deprivation may experience different cultural influences on walking behaviour. These interactions constitute a ''whole system' way of thinking.' (Curtis, 2004, p.22). According to Curtis (2004), 'Geography as a discipline is particularly well suited to the 'whole system' way of thinking, since geographers are concerned to examine the interactions between population and the environment, and how this varies across space and in different types of place.' (Curtis, 2004, p.22-23).

Thus, socioecological modelling can be used to demonstrate many of the key facets of health geography and will be used to support this research. The following sections discuss how socioecological models can be applied to health and physical activity, and how these can be used to inform this research. The chapter will begin by introducing the historical context of socioecological theory and modelling. Socioecological models of health, physical activity and walking will then be evaluated. The discussion section will develop a theoretical model to guide this research based on the evaluation of models considered in this chapter.

2.2 The development and principles of socioecological models

This section discusses the emergence of socioecological models and their contribution to interpreting human behaviours. Two different approaches to theorising and modelling behaviour will be considered, behavioural and environmental, before introducing socioecological theory and models. More recent developments in socioecological modelling will be discussed.

2.2.1 Historical context of socioecological theory and models

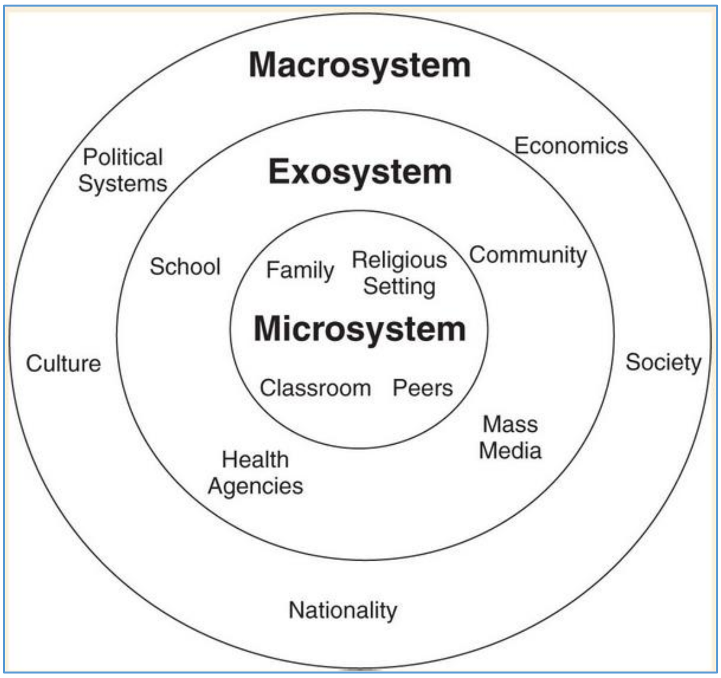
The idea that environments influence health has a long history. In the wake of industrialisation in 19^{th} Century Britain, for example, reformers such as Edwin Chadwick were convinced that improving the living conditions of the population would improve individual health (Lang and Rayner 2012). Chadwick was instrumental in improving housing and public sanitation for the working population to improve health outcomes (Porter and Porter 1990). In the late 1800s, Florence Nightingale, documented maternal mortality from puerperal fever, comparing outcomes between some of London's maternity institutions and home births. She found that mortality in institutions was higher than for home births, even after accounting for individual factors that could influence maternal health such as poverty levels and maternal age. She used this as evidence that the influence of institutional settings could outweigh individual susceptibility (McDonald 2001). However, by the time of the development of early formal models of health behaviour in the 1940s and 1950s, attention had shifted to an emphasis on the role of the individuals in shaping health, focussing on individuals' intentions, attitudes and perceptions as key determinants of health. Throughout the 1940s and 1950s, health was generally considered through the lens of a 'biomedical' model. This reductionist perspective promoted biological factors as the primary considerations for health and individual attributes over populations (Morris et al. 2006). Health was considered in a healthcare setting involving a relationship between an individual and a health expert (Russell 2013). To be healthy implied the absence of disease and ill-health seen as the realm of medical intervention. Behavioural models also focussed on individuals; examples of these include The Health Belief Model introduced in the 1950s (Rimer 2008) and Ajzen's Theory of Reasoned Action (c1975) which he developed into his contemporary Theory of Planned Behaviour (Ajzen 2002). Many successful medical treatments have been developed from such medical such as inoculations for life threatening diseases such and surgical treatments. However, for a time this perspective also dominated interventions for health behaviours such as physical activity (Giles-Corti and Donovan 2002, Stokols 1992). This meant that the majority of behaviour change strategies also focussed on individuals, such as walking clubs or worksite programmes (Saelens and Handy 2008). From the 1970s this was beginning to change and there was a resurgence of interest in contextual, or environmental influences on behaviour (Giles-Corti and Donovan 2002, Morris et al. 2006). There was an increasing recognition that health was more than just the absence of medical maladies, and increasingly came to be viewed in line with the original WHO definition of health as 'a state of physical, social and mental wellbeing' (WHO 1946, Stokols 1996). This meant that health issues were viewed outside of the narrow remit of medicalised settings and understood as a more holistic condition subject to diverse influences. There was growing concern about environmental detriments to health such as pollution as part of this wider agenda(Bickerstaff and Walker 2001), and a rising interest in the role of environmental health protection and disease prevention (Stokols 1996). Environmental health legislation began to come into effect, for example, restrictions in cigarette advertising in 1970s (Laugesen and Meads 1991). Additionally, it became increasingly apparent that empirical evidence for the efficacy of individually based behaviour change strategies on behaviours such as physical activity was weak (Giles-Corti and Donovan 2002); conversely environmental interventions are considered to offer the potential for longer-term effects (Stokols 1992). All this contributed to a growing sentiment that individualistic theories were limited through failing to account for environmental influences (Giles-Corti & Donovan 2002; Stokols 1996) and there followed a resurgence of interest in environmental influences on health and health behaviours, as observed in the mushrooming of literature investigating environmental influences on physical activity behaviours such as walking (Andrews et al. 2012; Bauman et al. 2012; Cummins et al. 2007; Sallis et al. 2008).

2.2.2 Principles of socioecological theory

Socioecological theory incorporates the influences of both environmental and behavioural and environmental approaches. In socioecological theory, health and health behaviours are considered a cumulative outcome of the ongoing interaction between individuals and multiple facets of their environment. This perspective began to emerge in the 1960s and has since been gaining momentum and support (Stokols 1996). There is no fixed definition of socioecological theory, it comprises an 'overarching framework, or set of theoretical principles' (Stokols,1996, p. 283). The following section will discuss these and some more recent trends in the field of socioecological modelling.

A key premise of socioecological theory is that behaviour is the outcome of interactions between individuals with their social and physical environments (Bauman et al. 2012, Sallis et al. 2006). Traditionally, the field of ecology focussed on relationships between organisms and natural environments. Socioecological theory places greater emphasis on social and institutional environmental factors and human constructed aspects of physical environments and social and human interactions with these (Stokols 1992). One of the earliest formal models of this relationship was published by Lewin in 1936. Lewin said that to understand behaviour we 'must take into account whole situations, i.e., the state of both person and environment' (Lewin, 1936, p.12). He defined behaviour (B) as a function (f) of the person (P) and their environment (E) using the formula B = f(PE). Lewin termed this combination 'psychological life space' *(ibid).* Lewin's model was an early formalisation of the interrelations between people and their situation for understanding behaviours, however, the scope of Lewin's model did not include specification of the characteristics of environments that influence behaviours. A key precept of contemporary socioecological models is that there are multiple dimensions of environmental influence on behaviour (Sallis et al. 2008). An early model showing the influence of multiple environmental characteristics was published by Bronfenbrenner in 1979 in his model of child development (Figure 1).

Figure 1 Bronfenbrenner's Model of child development



Source: Rayner and Lang, 2012

This model shows the individual at the centre of a concentric arrangement of influences. The influences operate at multiple levels at increasing distance from the individual. These are categorised in three types; the microsystem is closest to the individual and comprises immediate influences such as families and peer groups. Next is the exosystem which is external institutions and organisations such as school and community, and finally the exosystem, which is the overarching social environment such as cultural norms and political and economic conditions. Bronfenbrenner's conceptual arrangement has had considerable longevity and many subsequent socioecological models have been based on a similar principle (Dahlgren and Whitehead 1992, Sallis et al. 2006, McLeroy et al. 1988, Bauman et al. 2012, Spence and Lee 2003). By dividing environments into separate analytic levels it elucidates different types of influence and can be used as a guide for behaviour-change interventions, which is considered a key feature of socioecological models (Sallis et al. 2008). A limitation of this model is that it does not show the influence of individual attributes or characteristics, the influence of which are an important facet of contemporary socioecological theory (Stokols 1996). A variation on Bronfenbrenner's model was introduced by McLeroy et al. (1988) shown in Figure 2.

Figure 2 Model of the determinants of patterned behaviour

(1) intrapersonal factors—characteristics of the individual such as knowledge, attitudes, behavior, self-concept, skills, etc. This includes the developmental history of the individual.
(2) interpersonal processes and primary groups—formal and informal social network and social support systems, including the family, work group, and friendship networks.
(3) institutional factors—social institutions with organizational characteristics, and formal (and informal) rules and regulations for operation.
(4) community factors—relationships among organizations, institutions, and informal networks within defined boundaries.
(5) public policy—local, state, and national laws and policies.

Source: McLeroy et al. 1988

This model has five layers of what the authors consider to be the determinants of patterned behaviour which are intrapersonal, interpersonal, institutional, community and public policy factors. A key difference from Bronfenbrenner's models is the inclusion of intrapersonal factors comprising psychological characteristics of the person such as attitudes and behaviour (McLeroy et al. 1988). This shows that individuals may behave differently in the same context due to their personal attributes. Later models of this ilk have included additional intrapersonal-level characteristics such as demographics (Dahlgren and Whitehead 1992) and family situation (Sallis et al. 2006) which may impact on behaviours and influence individuals' relationship with their environment. This has led to more explicit consideration of inequalities. Most socioecological models imply that there may be inequalities in outcomes for example by acknowledging that individual factors such as age and sex. It follows that outcomes are likely to be different for different people in different types of places. More recently socioecological models have been produced that specify social and biological factors that contribute to inequalities in outcomes by showing them as moderators, mediators or direct determinants of outcomes. For example, in her 'Hierarchy of walking needs within a socioecological framework', Alfonzo (2005) shows that life circumstances such as biological and cultural circumstances moderate the relationship between environmental conditions and walking behaviour (Figure 14).

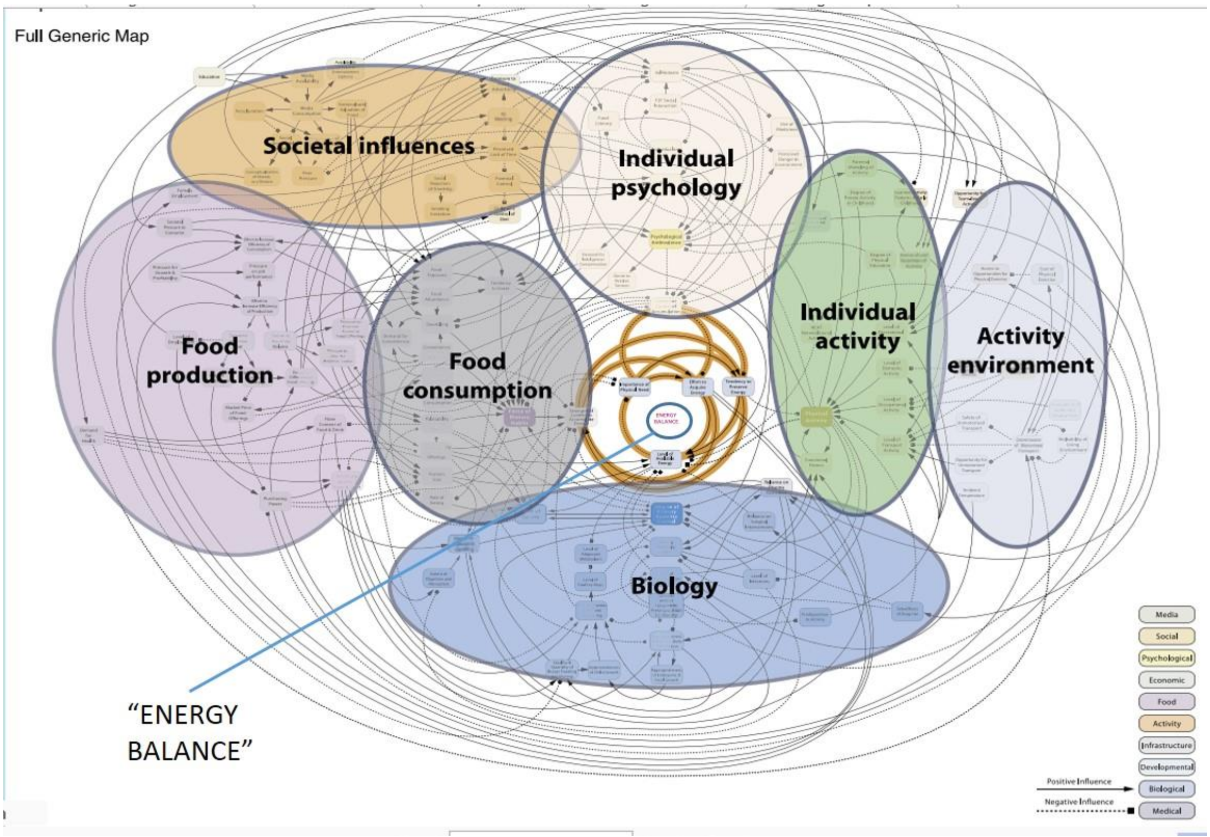
In socioecological theory the dynamic interactions between people and environments are conceptualised as part of a system, in which events are nested in a wider system of influences (Stokols 1992). These systems have been considered within the notion of 'complexity' which incorporates concepts such as path-dependency and feedback loops. A definition of complexity is offered by Rayner and Lang (2012):

In its modern conceptualisation complexity occurs when the elements of a system interact in a non-linear fashion… there is no necessary proportionality between causes and effects and it is impossible to predict system behaviour from only knowledge of the elements themselves. In a complex system there may be sensitivity to initial conditions, as well as numerous feedback loops and multiple chains of interaction.

Rayner and Lang, 2012, Kindle e-book edition

The Foresight model is an example of a model of a complex system of influence (Figure 3). It shows the system of connected influences on 'energy balance' and obesity.

Figure 3 The Foresight full obesity system map with thematic clusters



Source: Butland, 2008

NB. This figure is not intended to be fully legible but to show key dimensions and illustrate the complexity of the model

These influences are organised into seven thematic clusters, and within and between these clusters are a series of relationships which illustrate several aspects of systems models:

- Elements in the system are connected by causal relationships which may be positive or negative. Arrows show positive relationships (when one element increases, so does the other) for example food exposure may increase a 'tendency to graze'. Dotted lines show negative relationships where elements have an inverse relationship, for example, the relationship between level of employment and the desire to minimise costs.

- The model includes 'feedback loops' showing relationships that influence the overall outcome. For example, a feedback loop exists between energy accumulation (seeking and eating food) and energy use influencing the model's overall outcome of energy balance. If energy is used through physical activity, this triggers the body's need for energy accumulation through food consumption which brings the overall energy balance back to equilibrium. These loops can be overridden when people consciously or unconsciously increase or decrease their energy accumulation or energy use (Butland 2008).
- The model demonstrates how interventions or changes to one element in the model will have an impact on others, which can lead to intended and unintended consequences, an important principle of socioecological modelling.
- As with other socioecological models, this model shows 'levels' of influence. The key outcome, energy balance, is shown at the centre of the model, influences are shown at increasing distance from the centre, with elements closest to the centre considered to be the more influence. The author states that this can be used to guide policy interventions, by showing which types of influence are likely to have the biggest impact on the outcome. (Butland 2008).

The key features of socioecological models that have been discussed here are summarised in Table 1.

Table 1 Summary of key features of socioecological models

Feature	Explanation
Multiple levels of influence	There are multiple levels of influence on people and behaviours, which can include physical, institutional, social and cultural dimensions. Socioecological models identify how interventions at these different levels can influence outcomes; multilevel interventions are considered the most effective.
Interactions	Interactions exist between people and their environments and between multiple levels and dimensions of environments. This means that socioecological models incorporate multiple analytic and disciplinary perspectives, therefore they are inherently multidisciplinary.
Systems	Outcomes are subject to a complex 'system' of influences. Systems include concepts such as feedback loops, positive and negative interactions, path dependency and intended and unintended outcomes.
Inequalities	Different personal or area characteristics can shape outcomes leading to different outcomes for groups of people or for people living in different types of places.

2.3. Socioecological models and health

2.3.1 Introduction

In this section four socioecological models of health are discussed. These have been selected to demonstrate nuances in the ways that socioecological modelling can be used to understand population level health, and the strengths and limitations of socioecological models of health. These models are summarised in Table 2.

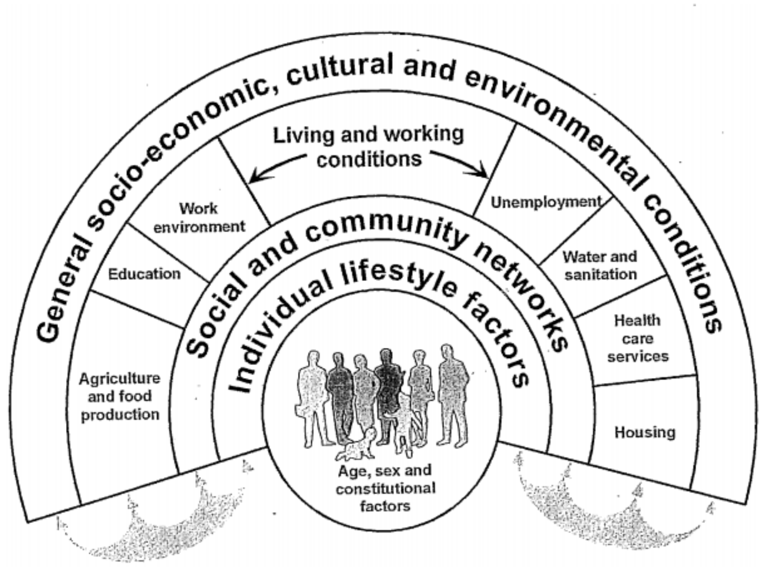
Table 2 Socioecological models of health

Author/ date	Model title	Model description	Outcome
Dahlgren and Whitehead, 2007	The main determinants of health	A concentric model showing individuals at the centre of layers of influence. The layers comprise individual factors, individual lifestyle factors, social and community networks, living and working conditions, general socio-economic, cultural and environmental conditions	Health
Morris et al. 2006	DPSEEA Model	A generic model of influences on health that can be adapted to different health issues. Shows a linear chain of causal influences from Drivers (higher level social economic or political influences on environments), Pressures (resulting from the drivers which change environments), State (the environmental state), Exposures (resulting from interplay between individuals and their environment) and Effects (on human health resulting from interplay between environmental exposures). All these can be influenced by Actions which can be taken to reduce exposure or health effects. Exposures and Effects are set within Context which comprises social, geographic, demographic and social components.	Effects on human health
WHO, 2010	Model of social determinants of health	Global model of social determinants of health inequity and wellbeing. Shows multiple dimensions of structural and intermediary factors. Structural determinants are social, cultural and political contexts and individual socioeconomic position. These interact with intermediary determinants which are material, biological, behavioural and psychosocial characteristics and the health system itself. Health outcomes can feedback into structural determinants, for example by influencing occupation and income. Interventions require complex intersectoral policy.	Health inequity and wellbeing
Krieger 2012	Embodiment of racial inequality and its implications for health inequities	This model shows unequal race relations shaping socio political, economic and ecological processes which become embodied as health inequities. These operate at various levels across the life course.	Racial/ ethnic health inequities

2.3.2 Review of socioecological models of health

The first model in Table 2 is Dahlgren and Whitehead's (2007) model of health. This is an updated version of their original model developed in 1983. This model follows the concentric arrangement of Bronfenbrenner's model, showing what the authors consider to be the main determinants of health (Figure 4). These comprise individual factors, lifestyle, social and community setting as well as general cultural and environmental conditions. The multiple layers are useful for identifying different types of influence on health, and aim to encourage health interventions to operate at multiple levels in order to maximise their impact (Dahlgren and Whitehead 2007). There are arrows linking all four layers external to the individual indicating interactions between all these levels, showing the influences on health as being an interdependent system. The arrows linking the different layers of influence are broad and non-specific, however, making it unclear how specific relationships occur.

Figure 4 Model of the main determinants of health

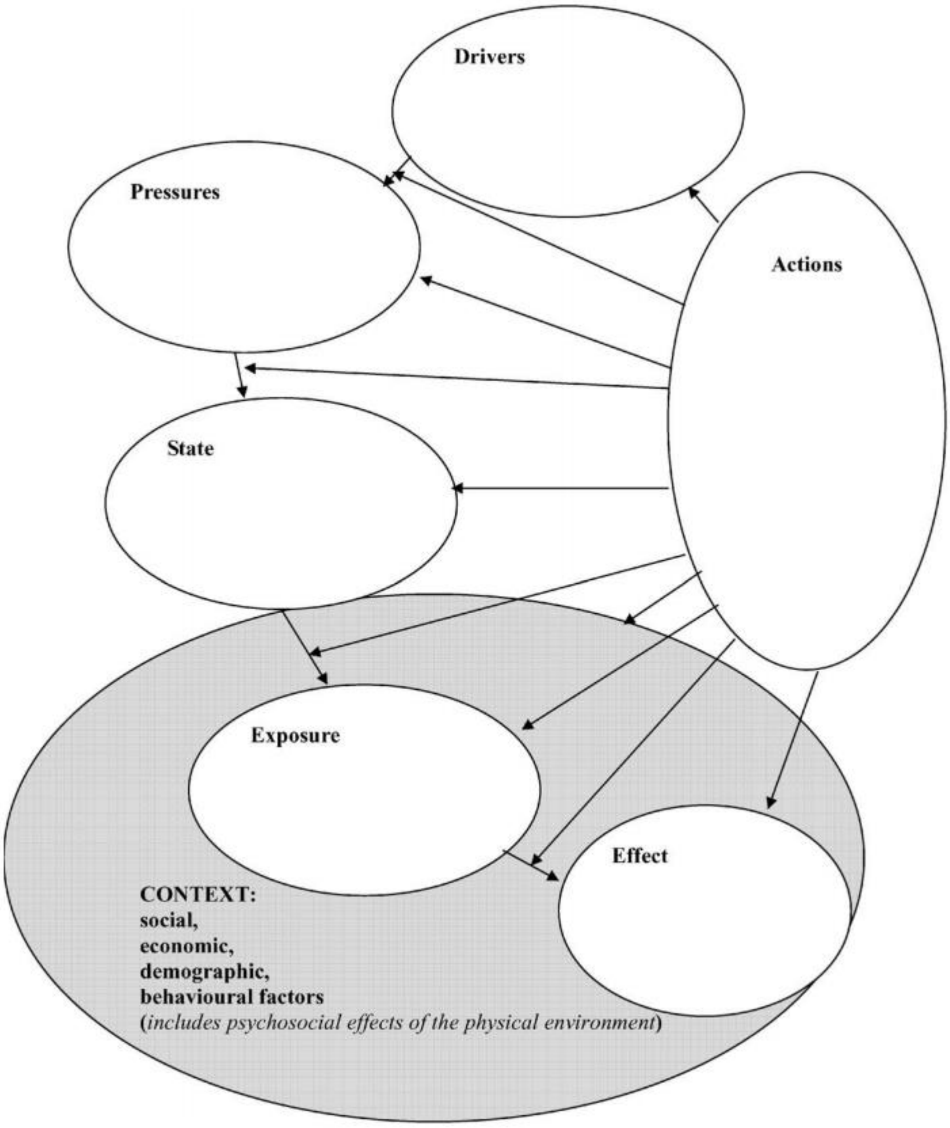


Source: Dahlgren and Whitehead, 2007

The model was published in a strategic policy document (Policies and strategies to promote social equity in health, background document to WHO Strategy paper for Europe, 2007), and so its aim is to help identify areas for policy intervention. This induced the authors to omit individual traits (for example, age, sex) showing as interacting with other levels of the model. The authors acknowledged that these factors play a part influencing health, but considered these are considered 'fixed factors over which we have little control' (Dahlgren and Whitehead, 2007, p.11). However, this means that important individual-environmental interactions are not shown, and individuals are depicted as inactive in the processes, environments happen 'to' them, rather than them being considered an active participant in the process. This leaves the model open to the critique of environmental determinism described in the previous section, and neglects to depict inequalities in outcomes that may result for some demographic groups. This is intended as a global model of influence on health, it has a broad scope and a comprehensive range of potential influences on health but would require adaptation to be used to guide interventions for specific health issues.

A model proposed by Morris et al. (2006) specifies causal mechanisms more clearly and shows the influence of individual characteristics and is shown in Figure 5, the modified DPSEEA model of health.

Figure 5 The modified DPSEEA model of health



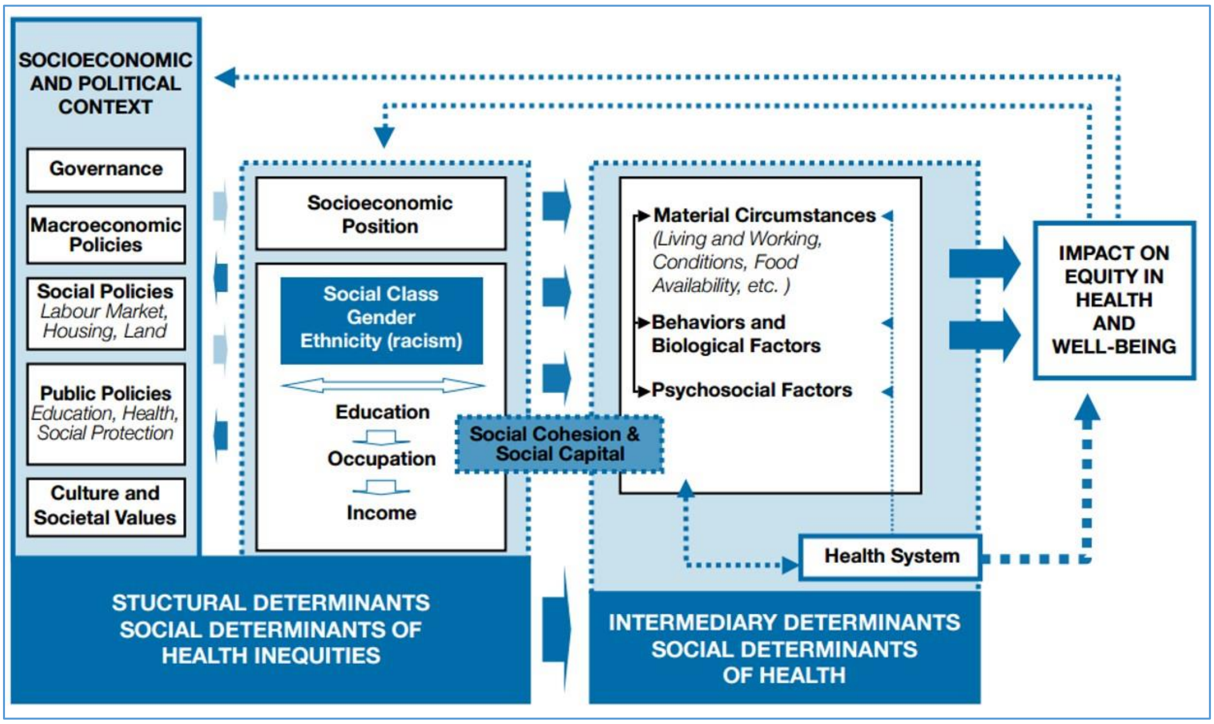
Source: Morris et al. 2006

This model is a modified version of one initially published by WHO and like Dahlgren and Whitehead's (2007) model, is proposed as a basis for strategy to improve health outcomes (Dahlgren and Whitehead 2007). This is a generic model of causal processes and environmental influences on health. It shows a linear chain of causation from high level social, economic or political influences (Drivers) which modify the environmental state which influences exposures and effects on human health. Actions can intervene at any stage of the process. Individual factors such as demographic and behavioural factors are shown as being part of the 'contextual bubble' which mediate the effects of environmental influences on health outcomes. This context includes psychosocial factors. Psychosocial refers to the influence of social factors on perceptions or behaviours (Martikainen et al. 2002). In this model, psychosocial factors are shown as mediating relationships between the physical environment and exposure and effects of health consequences.

This model demonstrates the multiple levels of influence and shows causal influences between levels of influence, This makes it clear to see how strategic actions can be taken to influence any of the levels in the model and interventions at higher levels, (such as political or economic policies) can have a knock-on effect at lower levels, making it a useful guide for policy interventions (Donnelley 2008). Indeed this model was incorporated into the Scottish Government's environment and health implementation plan, 'Good Places, Better Health' (Donnelley 2008). It shows chains of causality, making it possible to identify the source of health outcomes (Hambling et al. 2011). It can have practical application by adapting the specific components within each category to a particular health issue, and entry points for interventions are identified at each level (Fussel and Klein 2004). The model has been kept deliberately simple, showing linear and one-way relationships between the levels, except in the case of contextual influence, which are not specified. This simplicity is deliberate, since the authors argue that 'There seems little point in illustrating complexity at the expense of utility' (Morris et al, 2006, p.896). However, this simplicity comes at the cost. The influencing pathways of contextual factors are vague, making it difficult to see clearly the pathways through which such factors may affect outcomes. Interactions that may occur between levels are omitted, and it does not address feedback loops discussed in the previous chapter, and thus does not address the more complex associations between environments and health outcomes (Hambling et al. 2011).

Other models of health focus on health inequalities. One such model is the World Health Organization's model of the social determinants of health showing how existing social inequalities can influence health inequities (Figure 6) In this model societal structural determinants comprise policies and cultural values and individual socioeconomic positions (such as income, education, occupation, gender, race/ethnicity) which shape intermediary determinants of health (material, behavioural, biological and psychosocial factors and the health system) which impact on equity in health and wellbeing.

Figure 6 The WHO model of social determinants of health

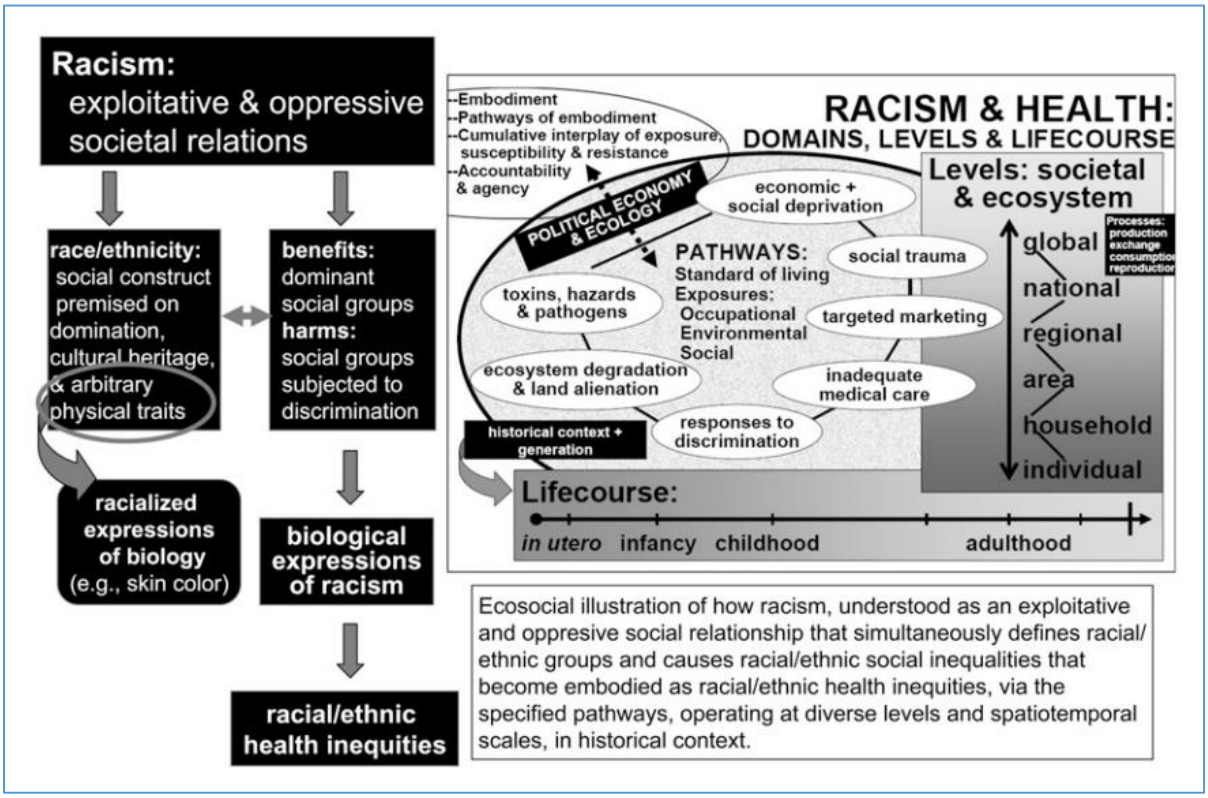


Source: WHO, 2010

This model shows multiple dimensions of structural determinants of health inequities, both higher level influences (governance, culture, policies) and individual level socioeconomic position. Dynamic interactions are shown between these two types of structural factors which both influence individual material, biological and psychosocial factors as well as health systems themselves which affect health outcomes. It includes feedback loops showing how health outcomes can feedback and influence socioeconomic contexts and individual socioeconomic statuses, for example ill health could have a negative impact on occupation and income (WHO 2010). The model embraces the complexity of health outcomes, although interactions between levels are limited to showing linear chains of causation between structural and intermediary determinants and health outcomes. The main limitation of this model is the exclusion of physical environmental influences, which is due to the deliberate focus on social determinants on health.

A subsequent model by Krieger (2012) (Figure 7) shows the impact of unequal race relations on health. She argues that race relations benefit the groups who claim racial superiority, racialize biology to produce categories to demarcate racial groups and generate inequitable living and working conditions, resulting in racial and ethnic health inequities. Major pathways involve economic and social deprivation, excels exposure to toxins, hazards and pathogens, social trauma, health harming responses to discrimination, targeted marketing of harmful commodities, inadequate medical care, ecosystem degradation and alienation from land. This model differs from the previous ones introduced by including a 'life course' perspective. A life course perspective accounts for how exposures to influences at different stages of life (from *in utero* and beyond) influence future trajectories and interactions with subsequent influences. It shows how historical context determines which pathways matter and are operative, at what level and at what point in the life course. This model demonstrates complex features of contemporary socioecological thinking showing complex interacting causal pathways between diverse levels of influence, taking account of spatio-temporal context and influence over the life course.

Figure 7 Schematic illustration as applied to analysing the embodiment of racial inequality and its implications for health inequities



Source: Krieger, 2012

This section has reviewed some socioecological models of health. Modelling an issue as complex and pervasive as 'health' requires an approach that can account for multifaceted influences. Using the WHO (1946) definition of health as 'state of physical, social and mental wellbeing' entails understanding these influences as operating at different levels. Socioecological models are good at drawing out such contextual influences on population health. The models discussed in this section demonstrate how such influences can range from physical, cultural, social, socioeconomic and institutional, operating at levels ranging from global to the individual. Dahlgren and Whitehead's model delimits these influences to five distinct spheres; the subsequent models show increasingly complex and detailed contextual influences. Different influences shown to be mutually interactive and reinforcing, showing how health influences at one level are inextricably linked to influences at other levels. For example, healthcare policies operating at a high level political context influence healthcare services, which form part of people's local material, social and cultural health environment level. By showing the connections between these types of influence socioecological models show how social, physical, and cultural aspects of environments interact and have a cumulative effect on health. (Golden and Earp 2012).

By depicting different levels of influence on health, the models can be used to guide health interventions for health improvement by identifying where such interventions are likely to have leverage and the type of intervention that is the most appropriate for a specific level. For example, an intervention at an individual level, such as a health education programme might bring about change in individual attitudes, whereas those at institutional level would be more likely to effect change in organisational environments (Golden and Earp 2012). This can be used to guide complementary multilevel interventions to bring about health improvement. This is important for health improvement policies because implementing change at multiple levels is more likely to leverage long term impact compared with single level interventions (Stokols 1992). Identifying diverse structural factors that can influence health highlights the role that different organisations have in improving population health. For example public or private sector organisations that can work alongside more traditional healthcare (Stafford et al. 2007). This in turn can influence health planning and highlights the potential for muti-agency working to deliver improvements in population health (Sallis et al. 2006).

Socioecological models can be used to develop understandings of health inequalities. By incorporating individual factors, they show how health outcomes are mutually constituted by environments and the people within them. This circumvents a deterministic approach to health, or purely emphasising individual-level determinants of health, showing that there are likely to be differences for different people in different places. This has implications for interpreting inequalities, since the consequences of environmental exposure are mediated by individual and group characteristics and psychosocial mechanisms, therefore, the same environmental exposure may have a different influence on some groups. Socioeconomic deprivation is associated with worse health outcomes (WHO 2010, Krieger 2012), which is a form of deprivation amplification; a double jeopardy of deprivation contributing to worsened health outcomes (Macintyre 2007). Understanding the pathways through which this double jeopardy occurs is important for understanding, and then tackling health inequalities. Socioecological models of health show interactions between different types of influence, such as socioeconomic status and physical environments. Some types of physical environments may mediate relationships between deprivation and health outcomes (Shortt et al. 2014), and in some circumstances may act as a mechanism for ameliorating inequalities (Mitchell et al. 2015). Environments that narrow inequalities have been labelled 'equigenic' (Mitchell et al. 2015) and it is important to develop understandings of these mechanisms for reducing inequality.

A disadvantage of socioecological models of health is that causal mechanisms are often poorly specified; which specific factors interact, and why they do so. Different models use different approaches to try to represent this complex issue. Morris' (2006) model, for example shows clear linkages between cause and effect showing an orderliness and giving the impression of predictability between cause and effect. Krieger's model shows a more diverse and complex arrangement of interactions, which makes it more difficult to perceive exactly how different interactions occur, but is a more realistic representation of the contingent and complex nature of influences on health. The spatio-temporal scale at which influences occur is not usually specified within models of health. While models acknowledge the different spatial scales at which influences can operate (global, national, regional, individual), the scale at which specific mechanisms operate is unclear. Scale can incorporate both spatial and temporal dimensions. It delimits the context in which action takes place, and is thus important for understanding associations between health influences and outcomes. Lack of understanding of the scale at which mechanisms operate can result in scale 'mismatches' between cause and effect making it difficult to identify appropriate interventions (Cumming et al. 2006). Krieger's (2001) model shows influences operating across the life course. This is important because environmental effects may be subtle, or there may be a time-delay between exposure and effect, for example, the relationship between smoking bans and improvements in health-related outcomes (Spence and Lee 2003). A 'life course' approach is increasingly incorporated into socioecological modelling (Bauman et al. 2012, Krieger 2001). This is based on the view that responses to environmental exposures exert a path dependency over the life course, and so exposures to stimuli at one stage of life can influence trajectories, and so influence outcomes or behaviours at a later stage of life. For example, prenatal and early life interventions aimed at women who have children with a high risk of obesity may reduce the chances of offspring developing obesity (Perez-Escamilla and Kac 2013).

There is a simplicity/complexity trade-off in modelling social processes. Broad comprehensive models can show multiple types of influence but lack detail. Detailed models can be more specific and act as a guide for practical research but are less likely to show all types of influence. Modelling a universal issue such as health means that specificity has to be compromised or the model would become impossibly complex (Marmot 2000). Narrowing the scope of models by focussing on particular issues allows for increased specificity (Sallis et al. 2008) and greater insight into influences and causal processes and scales of influence, and there have been calls for research into specific behaviours in specific environments (Giles-Corti et al. 2005). The following section will evaluate socioecological models that focus specifically on physical activity and then walking behaviour before developing a socioecological model of walking for this study.

These models contribute to understanding influences on physical activity, showing the types of diverse, interacting influences that can shape physical activity, as well as health outcomes. However, these are broad models, to understand physical activity greater specificity is required. This should include the type of contextual influence on physical activity and a spatial temporal dimension, showing at what spatial scales influences operate, and the trajectory of such influences over time. Moreover, models should take into account the specific individual and psychological aspects of physical activity behaviour. Rhodes and Nigg (2011) observe that while PA is likely to share many characteristics with other health and social behaviours, it also has some unique characteristics, these include, that it should be a regular activity over a lifetime, it requires considerable time commitment and environmental support and it can be achieved through various forms, arguably, each a unique behaviour. As such, the following section will evaluate models that focus specifically on physical activity and walking behaviour, and evaluate what these contribute to understanding influences on these behaviours.

2.4 Evaluation of socioecological models of physical activity and walking

2.4.1 Introduction

Socioecological models of physical activity (PA) and walking began to appear in the late 1990s (Spence and Lee 2003), some two decades after the initial development of the theory elsewhere, prompted by a growing awareness of the limitations of behaviour-based models (Rhodes and Nigg 2011). Disciplines that address physical activity (PA) and walking span medicine, urban planning and design, sport science, and, less frequently, geography. Traditionally, research carried out in medicine and sport disciplines focussed on individual-level determinants of PA rather than contextual influences (Pikora et al. 2003), whilst those in transport and urban design emphasised the influence of the built environment for maximising active living. Research in both fields has been criticised for lack of consideration of differences between different groups of people and types of places (Owen et al. 2004, Sallis et al. 2006, Bauman and Bull 2007, Das and Horton 2012). Increasingly, multi-disciplinary teams are carrying out research into built environment influences on physical activity behaviour (Alfonzo, 2005; Cerin et al., 2007; Owen et al., 2007). This avoids the restrictions of a single disciplinary paradigm facilitating consideration of more diverse built environment measures as well as wider social and individual influences on physical activity. Researchers across disciplines have embraced the socioecological model which, can be used to broaden these horizons, as discussed previously. The following section will review some of these models, beginning with models of PA, then models that show relationships between built environments (BEs) and walking and then those that focus on relationships between social inequalities and walking. These models are summarised in Table 3.

Table 3 Socioecological models of physical activity and walking reviewed in this chapter

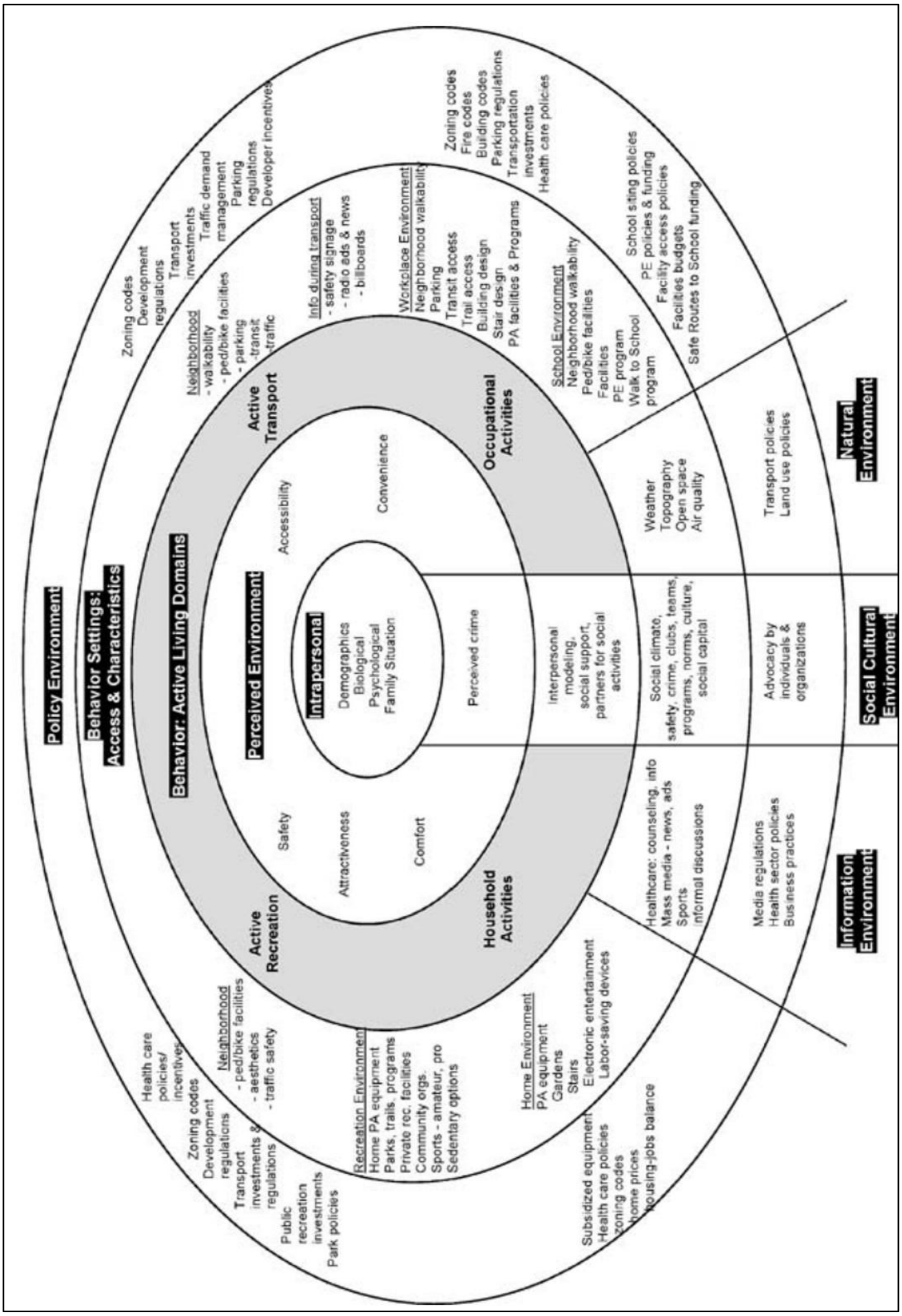
Author and date	**Model title**	**Model description**	**Outcome**
Sallis et al., 2006	Ecological model of four domains of active living	Multilevel model showing layers of influence on Active Living behaviour, comprising active recreation, household activities, active transport and occupational activities. Five layers of influencing factors: Intrapersonal and Perceived Environments, Behaviour Settings, Policy Environments and Social and Cultural Environments. Neighbourhood walkability lies within Behaviour Settings.	Active living behaviour
Bauman et al., 2012	Correlates of physical activity: why are some people physically active and others not?	Five categories of influence on PA; individual, interpersonal, environment, policy and global. Includes a life course trajectory indicating that exposures vary and have a different impact depending upon stage of exposure.	PA
Spence and Lee, 2003	Ecological model of physical activity	Shows environmental influences on PA as the macrosystem (e.g. societal values), exosystem (e.g. workplace support for PA), meso system (e.g. home influences) and microsystem (e.g. physical environment dimensions). Intermediary factors are biological and genetic and psychological factors. Physical ecology can influence PA indirectly via biological and psychological factors. Interactions between all types of environmental influences.	PA
Lee and Moudon, 2004	Conceptual framework for multidisciplinary research and policy for physical activity promotion	Connects three disciplinary perspectives; health science, transportation planning and urban design, showing these in relation to PA, specifically walking and cycling.	Walking and cycling
Giles-Corti et al., 2005	Examples of behaviour- and context-specific constructs for use within ecological models of context-specific behaviour	Show physical environment, social and individual influences on walking. Influences are shown to be behaviour and context-specific.	Walking
Saelens, Sallis, and Frank 2003	Ecological model of neighbourhood environment influence on walking and cycling	Specific features of neighbourhood BEs influence cycling and walking for transport and recreation/exercise. Influences are dependent on the motivation for cycling/walking. Environments are shown as having direct effects as well as being moderated by demographics and psychosocial correlates of PA.	Walking and cycling
Alfonzo, 2005	Hierarchy of walking needs within a social-ecological framework	Five levels of walking needs presented hierarchically as antecedents to the walking decision-making process. Moderators in the process are individual, regional or group level factors. Walking outcomes separated by motivation and duration.	Walking

Ewing et al., 2006	Conceptual framework showing perceptual qualities of urban design that can influence walking	Shows categories of urban design features that influence walking behaviours in categories that become increasingly subjective along the decision-making process. These are physical features, urban design qualities and individual reactions to urban design qualities.	Walking
Cerin et al., 2009	Hypothetical model of differences in walking for transport among SES groups	Model showing mechanisms through which individual and area level socioecological status might influence walking for transport. Mediators comprise individual, social and physical environmental features.	Walking for transport
Turrell et al., 2013	Conceptual model of the association between neighbourhood socioeconomic disadvantages, built environment, motor vehicle access and walking for transport	Model showing hypothetical association between neighbourhood socioeconomic disadvantages, BE, motor vehicle access and walking for transport. Potential causal pathways between socioeconomic disadvantage and walking as well as being mediated by the BE and motor vehicle access.	Walking

2.4.2 Socioecological models of physical activity

The following are models of PA (PA) showing multiple layers of influences on behaviour. Sallis et al. (2006) devised a model showing 'active living' domains (Figure 8) illustrating potential environmental and policy influences on four domains of active living: active recreation, active transport, household activities and occupational activities. This model uses a concentric arrangement like Bronfenbrenner's (1979) model. There are five levels of influence; intrapersonal and Perceived Environments at the centre, and Behaviour Settings, Policy Environments and Social and Cultural Environments as extra personal influences. The model includes contemporary phenomena such as the information environment, with influences such as the media promoting or dis-incentivising active living. The social cultural environment cuts across all levels, with variables such as social norms and social capital operating at the behaviour settings level, and advocacy by interest groups at the policy level. This illustrates the pervasive nature of some types of influence that can shape outcomes at different levels. The model also shows a range of intrapersonal factors that can influence active living behaviour which are demographic, psychological, biological and family situation, although there is no detail about what these are or how they interact with the rest of the model. Physical environments are distinguished from perceived environments in the model. This is important for two main reasons, firstly, perceptions of environments may exert a different influence on behaviours from physical environments, which is reflected in the model by showing these as separate layers of influence. Secondly, physical and perceived environments are likely to be influenced by different factors. The model shows perceptions being influenced by sociocultural factors such as levels of crime, or area SES, whereas physical environments are influenced by policies such as healthcare and land zoning policy. The strength of relationships between influences and behaviours is indicated by the relative proximity of influences to behavioural outcomes. For example, neighbourhood walkability is placed close to active transport behaviour, indicating that walkability is likely to have a strong influence on this behaviour. This useful for making connections between different types of influence on specific behaviour outcomes. The PA behaviours are positioned between behavioural settings (such as neighbourhood characteristics) and perceived environments (such as perceived attractiveness), indicating that these types of factor have the strongest influence. This is a detailed model showing a system of inseparable influences and outcomes. However, specific causal pathways or scales at which interactions take effect are not shown.

Figure 8 Ecological model of four domains of active living

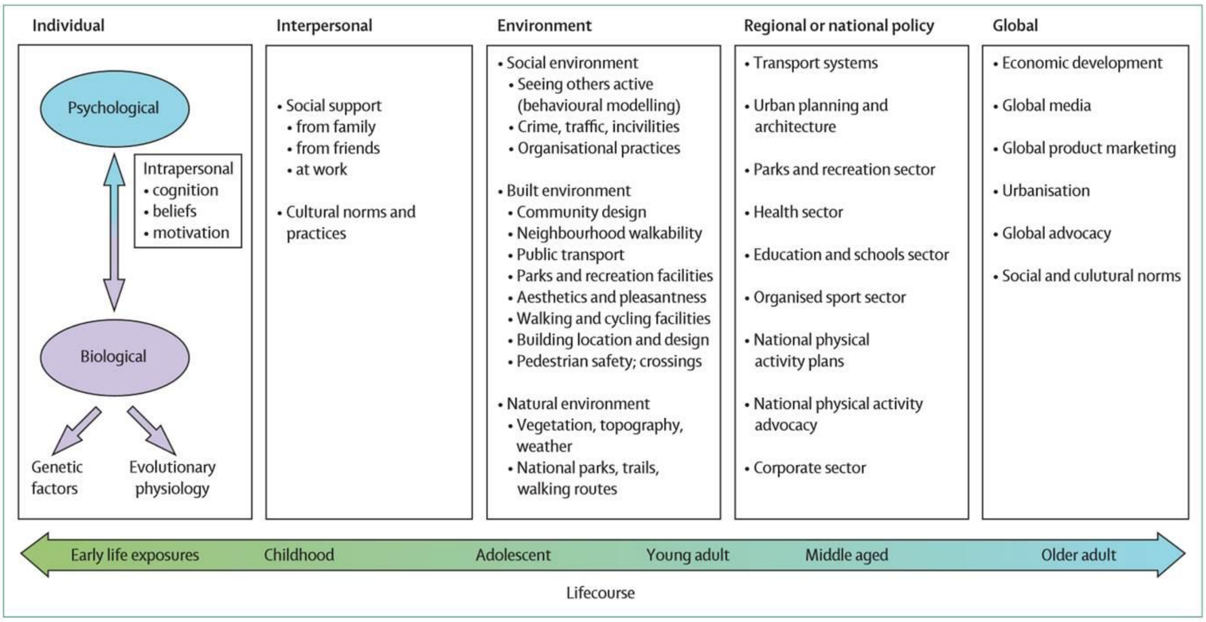


Source: Sallis et al., 2006

Bauman (2012) published a model showing five categories of influence on PA Interpersonal, Environmental, Regional and National Policy and Global influences

(Figure 9). As with the previous model relationships between the influences are not specified. The model includes a 'life course' trajectory, highlighting the importance of considering influences over the life course, although the pathways by which these effects occur are not shown. Individual level variables include biological and psychological factors. These are shown to interact, for example, individual characteristics such as age or gender may influence perceptions such as perceived safety or self-efficacy. The authors also consider less frequently studied aspects of biological attributes and their relationship with PA. For example, they discuss genetic factors suggesting that 'PA may be regulated by intrinsic biological processes' (Bauman et al., 2012, p.265) and genetic differences in reward systems or genetic make-up may contribute to differences in PA behaviour between individuals. They also discuss PA from an evolutionary biology perspective, suggesting that this could be the result of adaptation to mechanisation and culturally and technologically induced decreases in the need for energy expenditure (Bauman et al., 2012, p.266). There is limited exploration of causal pathways between the influencing factors and PA outcomes in the model, and no connections are shown between specific influences and PA behaviours or representations of scale. Instead, the main contribution of this model is showing different categories of influence on PA and the inclusion of less-frequently studied considerations, such as the role of evolutionary biological adaptation to environments. In addition, the model highlights the importance of considering whether people at different life stages are influenced differently by such factors.

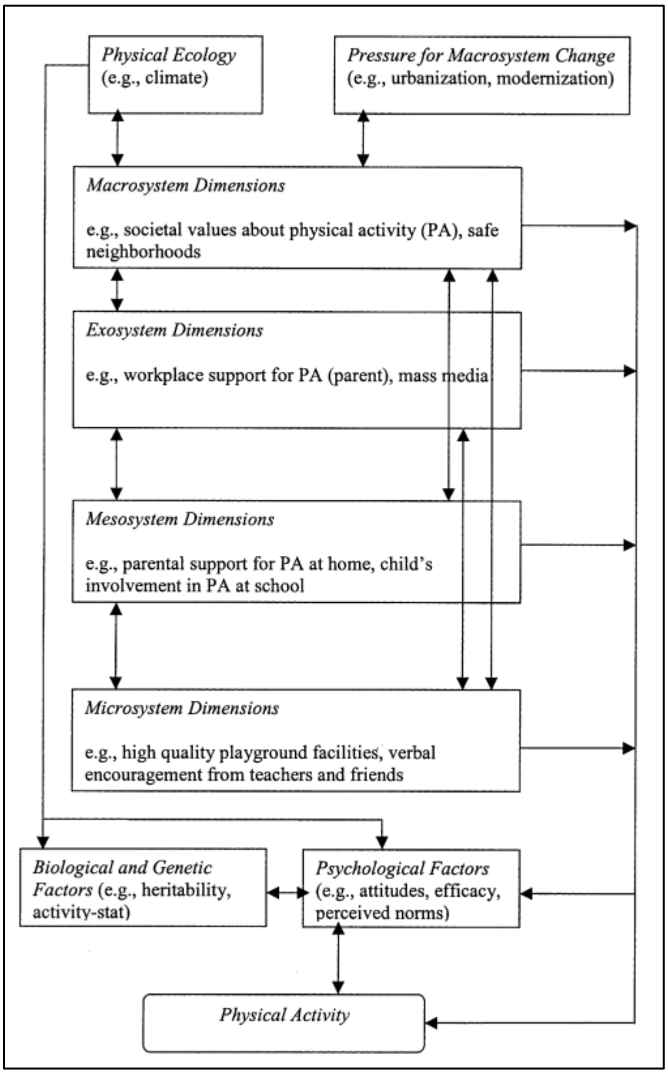
Figure 9 An adapted ecological model of the determinants of physical activity



Source: Bauman et al., 2012

A model by Spence and Lee (2003) (Figure 10) also considers broad categories of influence on PA. Based on the model by Bronfenbrenner (1979) , discussed previously, this model uses the categories of macrosystem (e.g. societal values), exosystem (e.g. media influence), mesosystem (e.g. involvement in school sports) and microsystem, which is the physical or social context of PA, such as workplaces, schools, homes or parks. The microsystem is shown as being the most proximal setting for PA. The model includes physical ecology such as climate change which can influence individuals and a 'pressure for change' which includes pervasive phenomena such as modernization and urbanization, showing how such higher-level influences can have an indirect influence on PA behaviour. These influences are intercepted by individual level psychological and physiological factors. Psychological factors are considered to have a more direct influence on PA behaviours because biological factors are considered to influence the type and extent of activity, whereas psychological factors such as cognitive constructs would influence whether someone undertakes any PA (Spence and Lee 2003, p.15). Again, this demonstrates the importance of a separate consideration of psychological variables which may hold different influence over behaviour than physical characteristics. Causal pathways are shown within and between influences on PA outcomes. Contextual influences are shown as having a direct influence on PA as well as a cumulative effect through interrelations with other contextual influences. This exposition of causal pathways lends the model greater explanatory value in terms of causal pathways than the two previous ones.

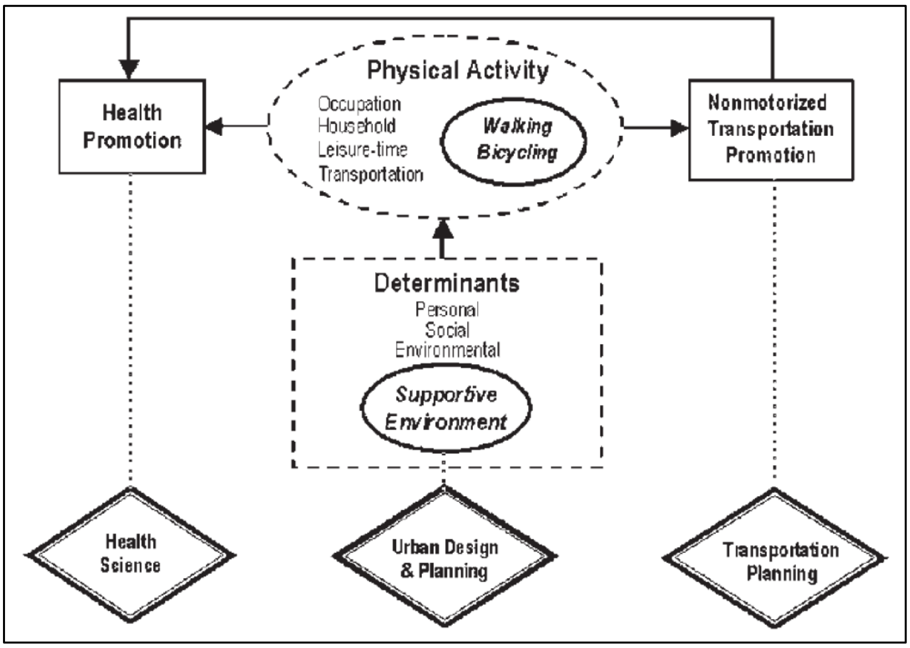
Figure 10 The ecological model of physical activity (EMPA)



Source: Spence and Lee, 2003

Lee and Moudon's (2004) model (Figure 11) takes an interdisciplinary focus, showing interrelations between the three disciplines of health science, transportation planning and urban design with PA. The aim of the model is to show the traditional contribution of each discipline towards implementing behaviour change strategies. The authors acknowledge that a rigid disciplinary separation no longer exists, but still identify urban design and planning as having the greatest potential to influence walking and cycling behaviour. This is because urban design has a direct effect on the contexts that support and contain walking and cycling and the authors consider that supportive environments have a direct influence on behaviour.

Figure 11 Conceptual Framework for Multidisciplinary Research and Policy for physical activity Promotion



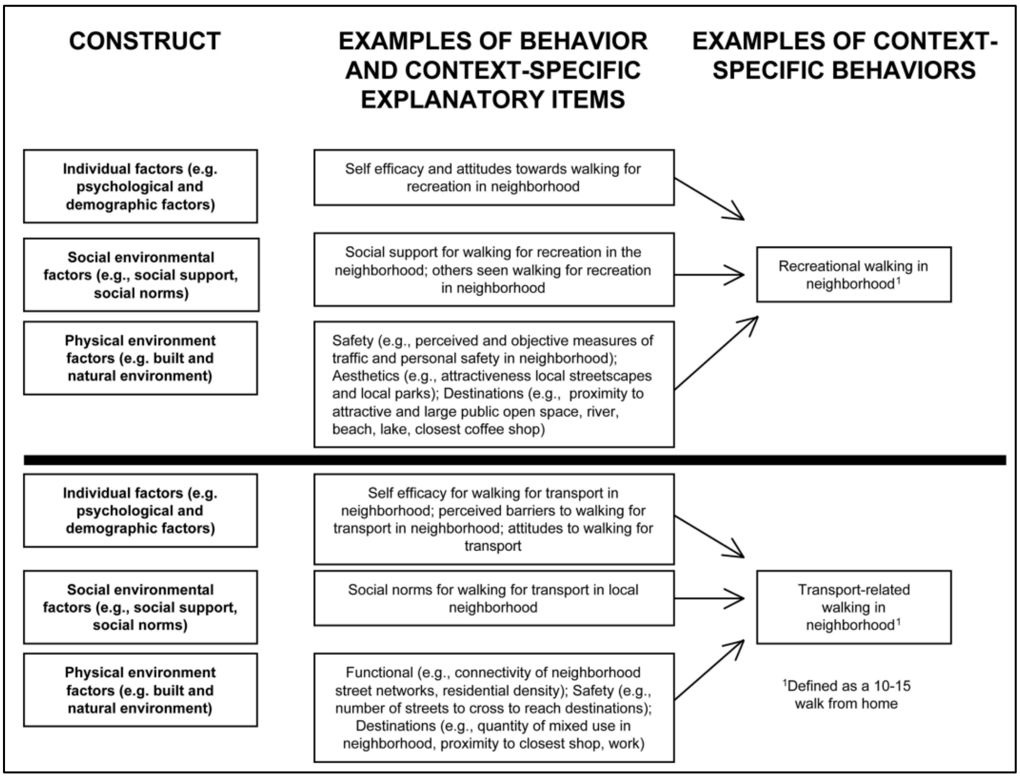
Source: Lee and Moudon, 2004

This complements the previous models discussed in this section which show multiple levels of influence on PA, but identify the PA behavioural context as having the most direct influence on PA behaviour. These models are broad in scope, and while they usefully situate PA within a wide system of influences, they do not identify causal links between specific influences and behavioural outcomes nor spatial scales at which these operate. As such they would require adaptation to be used to guide empirical research. The models discussed in the following section develop this theme. They have been developed to guide research and show specific features of exposure and walking behavioural outcomes and explore causal pathways in more detail.

2.4.3 Socioecological models of physical activity and walking

Giles'-Corti et al.'s (2005) model shows three types of influence, or 'constructs' on walking for recreation and walking for transport. These are individual, social and physical environmental (Figure 12). These constructs include various elements, the physical environment, for example, includes both built and natural resources such as traffic, safety and aesthetics. The authors argue that relationships between influences and behaviours are behaviour and 'context specific', and models should reflect this, ensuring that there are clear theoretical links between influences and outcomes. For example, correlates of active commuting are likely to be different to active transport in the local neighbourhood. This model specifies exposure scale as the local neighbourhood, defined as a 10-15-minute walk from home. The rationale for this scale is based on meeting recommended PA through walking (Giles-Corti et al. 2005, p.178). This means that positive relations found at this scale can be used to inform policies aimed at promoting walking through urban design. Individual and social variables are also particular to the walking outcome. For example, 'self-efficacy', an individual level explanatory factor, is specified as 'self-efficacy and attitudes towards walking for transport in neighbourhood' for the transport walking. This specificity can increase the predictive capacity of models by improving the match between exposure and outcome scales and variables (Giles-Corti et al. 2005). The inclusion of demographic, biological, and cultural variables indicates that this may influence walking outcomes highlighting that there may be differences in walking outcomes for particular groups.

Figure 12 Examples of behaviour- and context-specific constructs for use within ecological models of context-specific behaviour

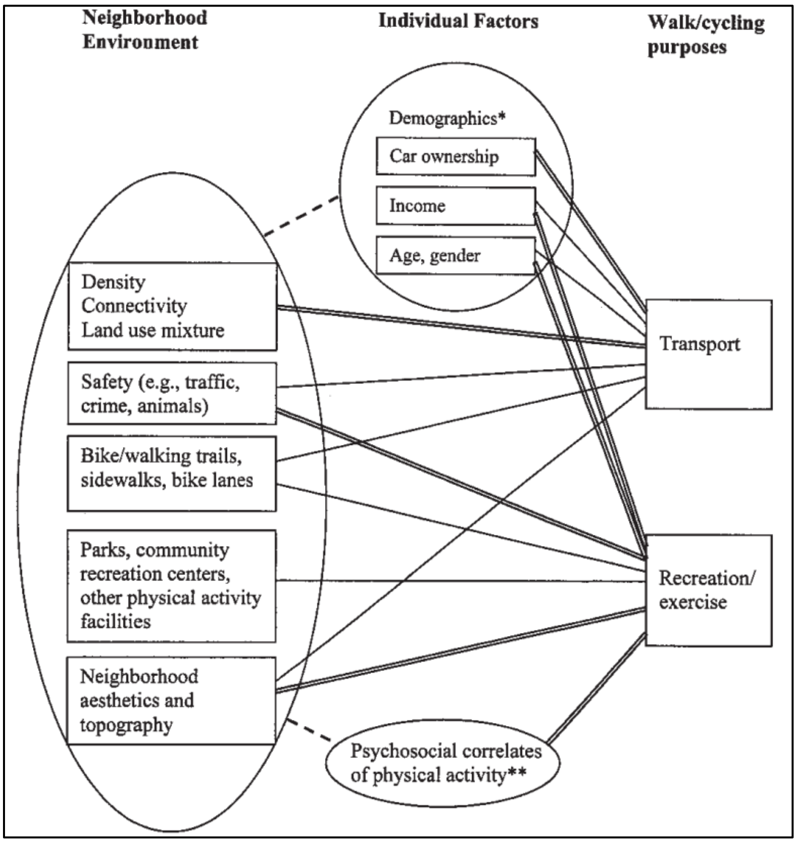


Source: Giles-Corti et al., 2005

The model does not show relationships between the three spheres of influence (social, physical and individual). Nor does it delimit which factors influence the behaviours or indicate the relative importance of the constructs or explanatory variables for understanding walking outcomes.

A model developed by Saelens et al. (2003) indicates the direction and strength of relationships between specific features of the BE with walking and cycling (Figure 13). It indicates different strength of relationships for neighbourhood environment variables and outcomes, showing some types of BE having stronger relationships than others, for example, aesthetics are more strongly connected to recreation walking than transport walking.

Figure 13 Ecological model of neighbourhood environment influences on walking and cycling



Double lines denote stronger relations; single lines denote weaker relations; dashed lines denote mediated relations.

*Some examples of demographic variables are provided, but should not be considered comprehensive.

**Psychosocial correlates of PA would include, but are not limited to, such variables as self-efficacy, perceived benefits, perceived barriers, social support, and enjoyment of PA.

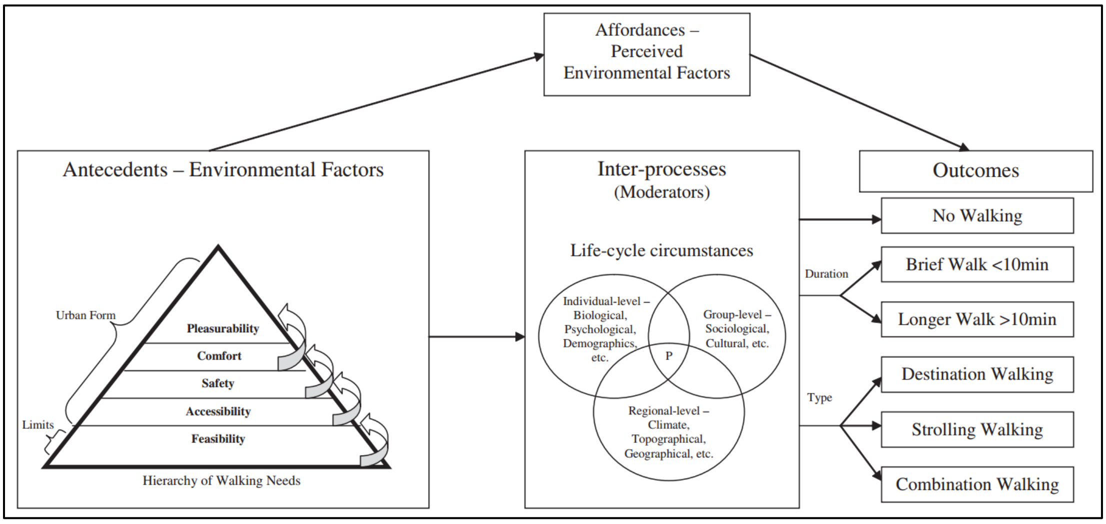
Source: Saelens et al. 2003

Walking and cycling outcomes are separated into walking/cycling for transport and walking/cycling for recreation because there will be different relationships between BE and walking/cycling depending on whether the walking/cycling outcome is for leisure or transport. This demonstrates the need for theoretical specificity between exposure and outcome. However, walking and cycling behaviour is not considered separately, which may overlook different motivations and associations for these separate behaviours. This model shows individual demographic and psychosocial factors mediating the relationship between the BE and PA as well as the direct influence of the BE. For example an individual who perceives a high benefit to being physically active may be more likely to be influenced by street connectivity than someone who has less positive beliefs about PA (Saelens et al. 2003, p.88). This highlights the potential for inequalities in relationships between the BE and walking for people with different characteristics. The model also includes context specificity, specifying neighbourhood level BE features as influencing outcomes, although the scale of the neighbourhood nor the behaviour is not specified. Car ownership is included as a mediating factor in relationships for transport walking since this is likely to present a valid alternative for travel where accessible.

Another model specifying the relative importance of different factors for walking is Alfonzo's hierarchy of walking needs model (Alfonzo 2005) shown in Figure 14. Alfonzo argues that decisions about walking are based on how far 'needs' are met. The most fundamental of these is feasibility, followed by accessibility, comfort, safety and pleasurability in decreasing order of importance. Feasibility is concerned with whether a walking trip is feasible, based on factors such as personal mobility and having time to make the trip. The author suggests the use of proxies to measure feasibility, such as the number of children in household or personal mobility. However, it is unlikely that these would capture the nuances and personal contingencies of personal assessments of feasibility, making this a difficult concept to measure effectively. The remaining 'lower order' needs manifest as urban features. Accessibility features include physical environmental features such as street connectivity, proximity to destinations and walking related infrastructure. Safety refers to whether an individual feels safe from crime, which is followed by the need for comfort, which includes the ease and convenience of walking and can be measured using factors such as traffic calming, street width and street furniture. Finally, pleasurability refers to the locational appeal for walking, such as aesthetic appeal. The selection of BE factors based on needs represents a novel and more sophisticated selection of variables than those based on empirical evidence alone since the latter method risks reification of the importance of commonly selected measures without adequate theoretical justification.

The model shows moderating factors between needs and walking which comprise individual, group and regional level factors. Individual factors include biological and demographic factors described as 'life cycle circumstances' that could influence decisions about walking. Cultural belief systems (for example on the importance of walking) and regional level variables such as temperature and climate are also considered to moderate relationships between needs and decisions about walking. By integrating individual and collective subjectivities, the model avoids a deterministic approach to relationships between environments and people's walking behaviour. The inclusion of regional and cultural level factors shows how such relationships may be contextually and culturally specific. This model shows variation in walking outcomes; Alfonzo suggests that when more needs are met people may be more inclined to do longer walks. Certain types of needs may be more salient depending on the motivation for walking, for example, pleasurability may play a bigger part in the decision to stroll (recreation walking) compared with destination walking (walking for transport). The potential of different environmental features to engender different walking behaviours is reflected in the model.

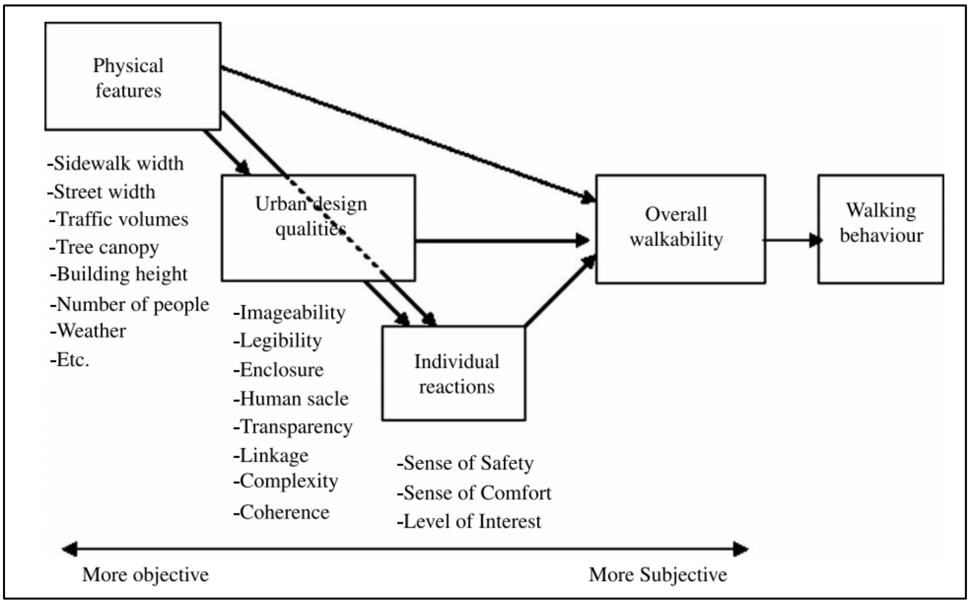
Figure 14 The hierarchy of walking needs within a social ecological framework



Source: Alfonzo, 2005

A model by Ewing et al. (2006) shows subjective qualities as intermediary factors between the physical BE and walking (Figure 15) This model develops variables to measure perceptions of urban environments that may influence walking. The measures were selected using ratings from an expert panel (Ewing and Handy 2009). Some of the types of measures are contestable, however, for example, the concept of 'enclosure' as a positive feature of urban environments, making open space appear room-like, which is considered to instil a sense of identity and 'hereness' (Ewing and Handy, 2009, p.73). By contrast, in other literature positive associations have been made between walking with a sense of openness (Zhang and Li 2011) and access to open spaces (Owen et al. 2004). Ewing and Handy argue that it is important to develop operalisationable measures of perceptual qualities; however, some of these would be quite difficult to incorporate into research. For example, one of the measures of enclosure is 'the proportion of long sight lines' but this measure could be very difficult to implement in practice limiting the usefulness of such concepts for empirical research. The model shows clear causal pathways between physical and subjective measures of the BE. It does not incorporate scope for perceptions being influenced by individual or group characteristics such as age or gender or cultural factors and spatiotemporal contingencies are not considered.

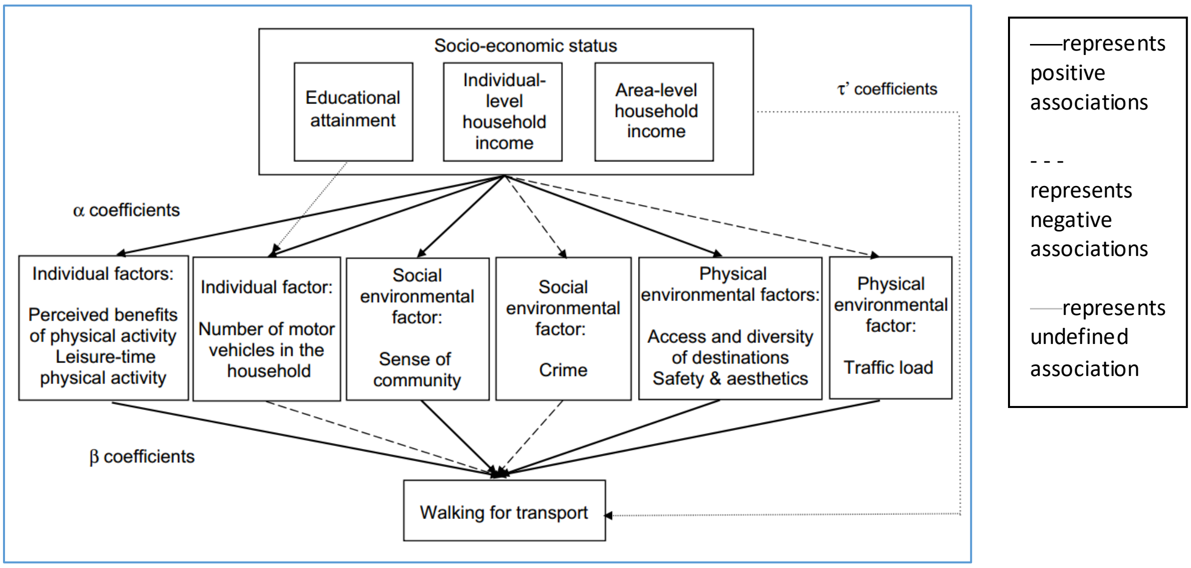
Figure 15 Conceptual framework of physical and perceptual qualities influencing walking



Source: Ewing et al., 2006

Some models focus on social inequalities as the drivers of PA outcomes. Differences in PA and between for people with different socioeconomic status (SES) or living in areas with different levels of deprivation have been found (Leadbetter et al. 2014; Shortt et al. 2014). The causes of these associations are not always well understood (Shortt et al. 2014) but have been hypothesised to be due to differences in physical environments, such as the quality of facilities (Ellaway et al. 2007) as well as psychosocial mechanisms (Lehto et al. 2013) which are explored in more detail in the subsequent chapter. The two models discussed below were developed to support research investigating whether such differences can be explained by intervening variables such as features of the BE, or whether social inequalities influence outcomes independently. Cerin et al.'s (2009) model (Figure 16) was used to investigate relationships between separate measures of SES and to examine the influence of a range of mediators on each measure. Six measures of individual, social and physical factors are included as indicators. The authors wanted to ascertain whether the mediating variables had a uniform influence across the SES measures to see which interventions might be the most effective for reducing health inequalities. For example, whether improving area aesthetics, would have a uniform influence on different SES groups or whether this influenced some group more than others. The model shows pathways of potential relationships between the factors (apart from the undefined relationship between educational attainment and car ownership), although the influencing variables are not set within a wider context of influences (such as policy interventions). The research aimed to investigate the influence of each of the mediating variables, and so the model shows separate pathways between each SES and mediator variable. Thus, it does not account for the potentially cumulative influence of different factors, such as the combined physical and social environments which may influence outcomes differently from a single measure.

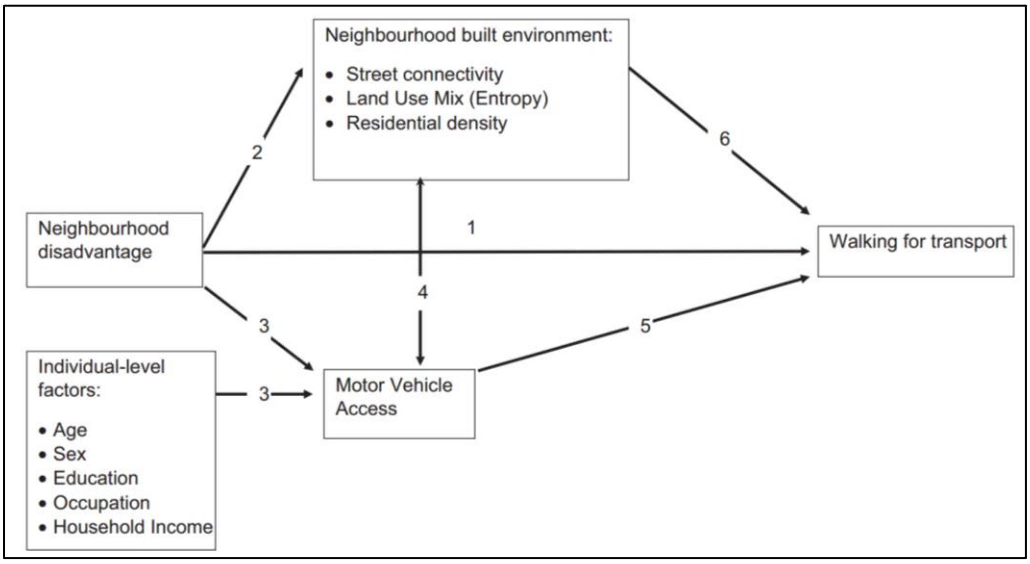
Figure 16 Hypothetical model of differences in walking for transport among SES groups



Source: Cerin et al. 2009

Turrell et al. (2013) published a model to investigate the contribution of the BE and motor vehicle to differences in walking for transport between advantaged and disadvantaged neighbourhoods (Figure 17). The model indicates several causal pathways which form the basis of the research questions, clearly indicating distinct causal pathways considered in the research, although the influence of the individual level control factors is less clearly displayed. As with to the previous model, however, the combined influence of mediators is not considered.

Figure 17 Conceptual model of the association between neighbourhood socioeconomic disadvantage, the built environment, motor vehicle access and walking for transport



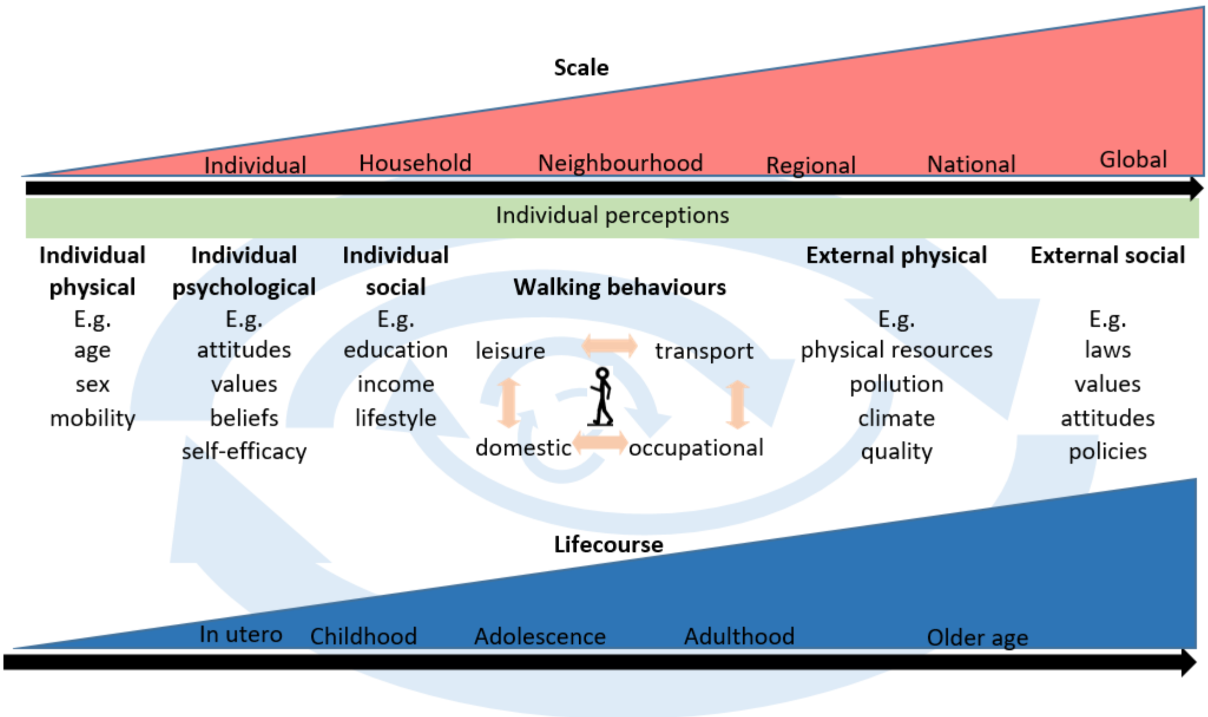
Source: Turrell et al., 2013

The models of physical activity and walking have demonstrated the diverse influences on physical activity and walking. Models that focus general physical activity outcomes have greater capacity to show a range of extra personal influences on physical activity. However, these tended to be more limited by their capacity to demonstrate specific causal pathways, spatial scales of influence and the relative importance of different influences on behaviours. Models that focus on walking have a greater capacity to show specific influences, and to indicate the relative importance of influences. Some of these have also shown the spatial scale at which influences operate. Models that attempt to order BE factors in terms of are most likely to facilitate walking (Saelens et al. 2003; Alfonzo 2005) are useful since this can inform policies and local decision making. The ordering of the BE factors can be assessed through assimilation of empirical evidence and research which is discussed in the subsequent chapter. The models including intermediary factors influencing relationships, highlight how relationships between contexts and walking can vary between different people and different social and spatial contexts, which provides useful guidance for researchers exploring variations and inequalities in relationships. The models that specify walking outcomes by motivation or duration and those that consider the scale at which relationships occur increases the specificity of the models and can help to guide research to 'match' exposures and outcomes facilitating the exposition of relationships between the BE and walking (Giles-Corti et al. 2005). These models of walking have been produced to guide specific research and therefore focus on a small number of influences on walking. This means that details about the wider systems of influences has been omitted. When evaluating evidence, it is important to situate results within a wider framework of influences at different levels, as shown in the models of multiple influences on PA. However, while more complex models might elucidate more channels of influence with increasing specificity would ultimately become impossibly complex to operationalize (Marmot 2000), whereas more focussed and detailed models can be used as a basis for specific research.

2.4.4 A conceptual model of walking

Using the ideas discussed in this review, a conceptual model of influences on walking was devised (Figure 18). The model includes the key tenets of socioecological theory; multiple levels of influence, interactions between different influences, complexity and the potential for inequalities in outcomes.

Figure 18 A conceptual model of influences on walking



This model incorporates Lewin's (1936) principle of B=f(PE) (behaviour is a function of the person and their environment). It displays walking behaviours in the centre of the model surrounded by individual and external influences, indicating that walking is a product of individual and external factors. The model reflects the socioecological theory principle of different levels of influence on behaviour showing individual, physical and cultural levels of influence. Individual characteristics are shown on the left. These are physical (such as age or mobility), psychological (for example, perceptions of fitness or ability) and social (for example, levels of education). Physical influences include factors such as the built environment. External social influences are non-physical factors such as whether walking is considered socially acceptable and policies that influence walking.

Individual perceptions are shown as having a ubiquitous influence in the model, since individual perceptions, whether conscious or unconscious, are considered to precede behaviour. This is similar to the model by Sallis et al. (2006) which shows perceptions of environments such as safety, comfort and aesthetics as a separate layer of influence on active living behaviours. This shows that perceptions also influence at individual and social levels as well, for example, perceptions of one's individual fitness and perceptions of social acceptability of walking will influence behaviour.

Four heuristic categories of walking are based on different motivations for walking, these are transport, leisure, occupational and domestic. These walking 'types' are shown with interchangeable arrows to depict that these are not always distinct from one another but are heuristic categories. For example, someone a walk taken primarily for leisure may involve picking up some shopping as an afterthought.

There are arrows underlying the model, which aims to show a myriad of continuous interactions between different influences at different scales at all levels of the model. This reflects the socioecological principle of multiple interactions between people and their environments. The different sizes of the arrows represent the multiple levels and scales at which interactions occur. This shows a complex system of influences which may include feedback loops, positive and negative interactions, path dependency and intended and unintended outcomes. Such interactions can result in inequalities in walking outcomes, for example certain individual or area characteristics can moderate or mediate walking.

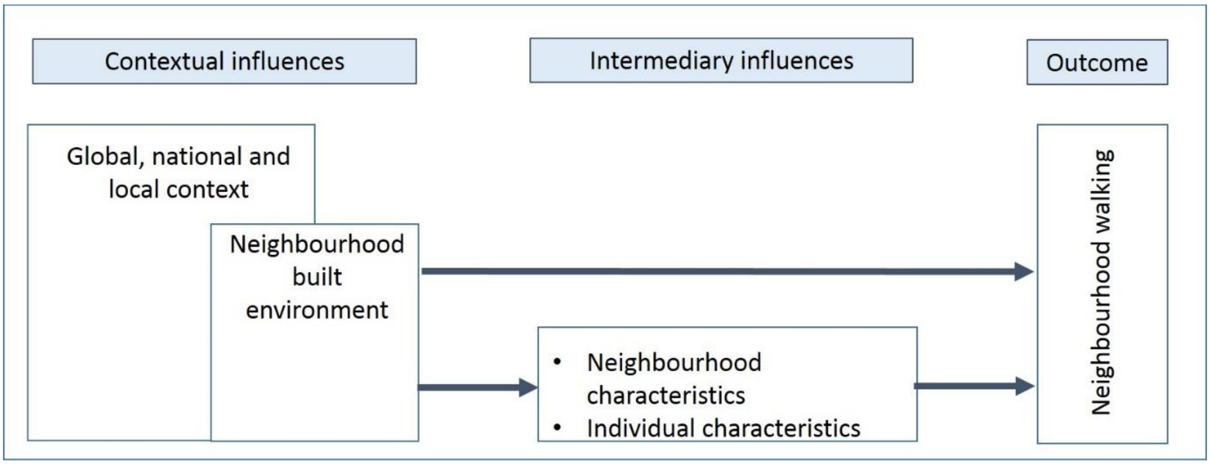
The scale at which interactions between people and their environment that influences walking can occur at multiple different scales. Such context specificity of influences is depicted at the top of the model, showing the varying scales at which influences operate by a continuously increasing triangle. Examples of the scale of where interactions might occur are shown to include household, neighbourhood, national and up to global levels such as global advertising and international policies. Such scales are not fixed, and may differ between individuals, for example peoples' perceptions of what constitutes their neighbourhood may vary. There is not necessarily proportionality between cause and effect, influences that operate at one level may impact at a different level, for example policies that are effected at national level may influence behaviours of individuals within their neighbourhoods. This model aims to give an overview of such different scales of influence.

It includes a lifecourse perspective. Drawing on the work of Krieger (2012) it shows a life trajectory, with examples of different 'life stages' is shown along the bottom of the model. This represents how influences and experiences that occur at one stage can affect behaviour at later stages. For example, someone who is exposed to a supportive walking in childhood and adolescence may develop habitual walking behaviour that they carry with them into adulthood.

This model aims to give an overview of influences on walking and so it sacrifices specificity for broadness. In attempting to give an overview of all potential influences on walking, it is inexplicit, and could be applied to almost any type of behaviour. As such, this model does not show specific influences on walking, causal pathways nor scales at which these occur. Therefore, to use this model as a basis for this research involved reducing its scope and developing specific categories of influences and outcomes.

The focus of this research is to investigate the influence of the built environment (BE) context on walking and inequalities in these relationships. The model used in this research is shown in Figure 19. It takes one aspect of influences, that of physical resources in the form of the built environment. It is a linear model showing the BE on the left and walking as an outcome on the right. In the centre are intermediary influences. Both individual and area level factors have been selected for their potential to exert this influence which could result in unequal relationships between the BE and walking for people who have different characteristics or who live in different types of area. The scale selected for this model is neighbourhood context, since local neighbourhoods often provide the contexts for walking that takes place from or to peoples' home.

Figure 19 Model of the relationship between the built environment and walking to be used in this research



The role of wider contextual influences is included in the model. Although these do not form part of the research methodology they are included in the interpretation and implications of the research in Chapters 7 and 8.

This model sacrifices the complexity and broadness of the model in Figure 18 to create a model that can be directly applied to this research question. It does not include scope for the influence of a life course perspective, that is, how the influence of the BE at one stage of life may affect relationships between the BE and walking at a later stage. However, age group or life stage can be included as an individual intervening variable and so different outcomes between the BE and walking for people in different age groups will be detected.

2.5 Summary

This chapter has shown the historical development of socioecological theory and reviewed its application to modelling health, physical activity (PA) and walking. The purpose of modelling is to show relationships between phenomena which can be used to guide research. This chapter has shown that influences are multi-layered, forming part of an interactive system whereby contextual and individual level influences interact and feed back to affect outcomes. Contextual influences operate at multiple levels and can have direct influence on outcomes, as well as indirectly, whereby influences are mediated or moderated by other factors. This can lead to inequalities in outcomes due to structured differences in outcomes for different people or places. This chapter has shown that models of broad concepts such as health or physical activity can contextualise outcomes in a system of multiple layers of influences, although causal mechanisms are often poorly specified. Models which focus on specific outcomes such as walking have greater potential to incorporate the relationships between specific influences and outcomes and specify the scale at which such interactions occur, and can be used to guide empirical research. The review of these models has been used to develop a model specifically to guide this study, which shows the influence of the built environment on walking, and intervening factors of individual and social environments. The next steps are to identify the specific characteristics of the built environment and intermediary factors that are likely to influence walking outcomes, and to define the most appropriate walking outcomes and scale for measuring the 'neighbourhood'. This will be developed through theoretical reasoning and a review of the empirical evidence, which is the subject of the next chapter.

Chapter 3. The built environment and physical activity: A review of the literature

3.1 Introduction

3.1.1 Background and purpose of the chapter

The purpose of this chapter is to appraise the evidence of relationships between different features of the built environment (BE) with physical activity (PA). There is an extensive international literature considering built environment influences on physical activity and walking. This review will begin by examining the evidence of associations between different types of BE measures with physical activity. It will summarise the strength of the evidence of relationships between specific features of the BE and PA, differences in these relationships for different groups of people and areas with different socioeconomic status. The final section will consider a range of methodological issues involved in the study of these relationships including study design, exposure scale, type of BE and PA measures and the location of research. By identifying features of the BE that may influence walking in Urban Scotland this review will guide the selection of BE measures to be used in this study. This will address the thesis aim to identify and create small area measures of features of the built environment considered to represent Area Walking Potential (AWP) across urban Scotland.

3.1.2 The scope of review

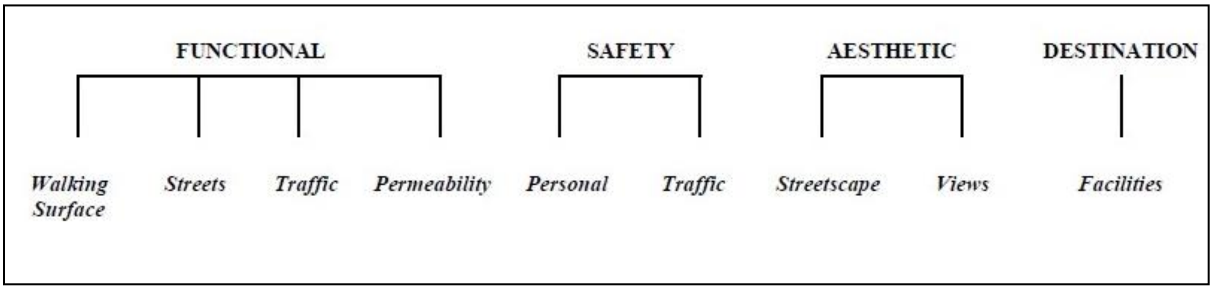
The built environment can defined as including any part of, or perceptions of, the physical environment that has been created or delimited by humans (Papas et al. 2007). The definition of the built environment used in this review will be restricted to external measures of the built environment. This means that indoor built environments such as the availability of staircases are not included. It will also exclude more organisational and policy-related factors, such as traffic calming measures. There are three main approaches to measuring the built environment for physical activity or walking. One is to measure perceptions of their environment, elicited via surveys or interviews, another is to carry out observation measures using systematic profiling of built environments, or street audits. The final approach uses secondary data sets of environmental characteristics to create objective measures (Brownson et al. 2009). All types of literature are considered in this review.

Physical activity is defined as 'any bodily movement produced by skeletal muscles that requires energy expenditure' (WHO 2010b). The behavioural outcome of interest in this research is walking, however, much of the literature relates to more generic outcomes such as physical activity or active travel, all PA outcomes will be considered here to ensure that relevant evidence is included. A common distinction made in the literature is differentiating between the concepts of leisure and 'utilitarian', or 'active travel' physical activity. The former refers to physical activity taken for its own sake, whereas utilitarian physical activity is activity people carry out as part of their day to day life such as walking to shops or cycling to work (Handy 2002). This research focuses on adults' PA so papers that focused exclusively on children's PA were not used. Evidence was gathered from online databases; Edinburgh University online library collection, PubMed, and Google Scholar. No date restrictions were applied but most relevant material was published since 2000.

3.2 The evidence – relationships between the built environment (BE) and physical activity (PA)

There is a huge volume of literature relating to the built environment and physical activity. To help navigate this, the framework proposed by Pikora et al. (2003) will be used to organize the evidence. This framework is shown in Figure 20. It divides the built environment into functional aspects (those relating to navigation of the environment), destinations, safety and aesthetic features. These are reviewed in turn below.

Figure 20 Model of the physical environmental factors that may influence walking



Source: Pikora, Giles-Corti et al. (2003)

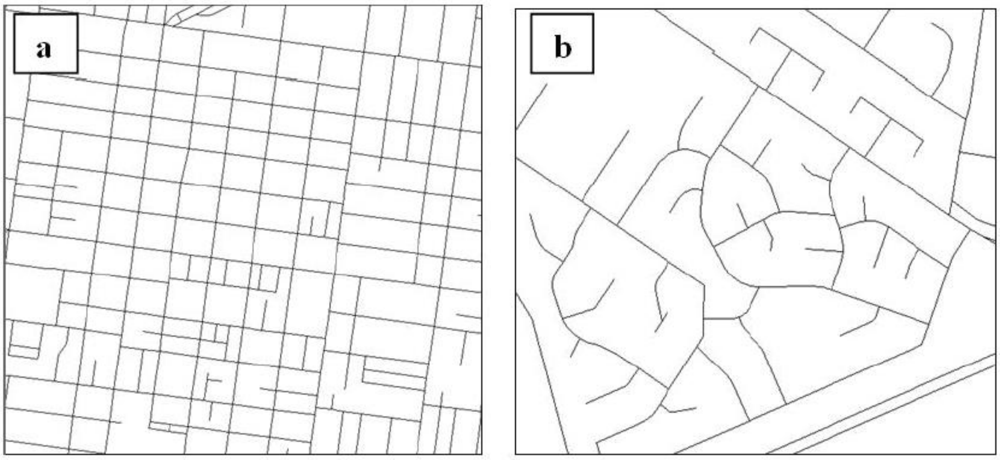
3.2.1 Functional measures of the built environment

Functional factors are structural aspects of the local environment that facilitate or impede pedestrian navigation (Pikora et al., 2003). Evidence relating to street connectivity, the availability of trails and footpaths, pedestrian infrastructure, density and sprawl and foreshore improvements are discussed below.

3.2.1.1 Connectivity

Connectivity relates to the permeability of streets, it can be defined as the directness and availability of alternative routes from one point to another within a street network (Handy et al. 2002). It is hypothesised to support walking because it can provide more direct navigation making trips shorter with more direct travel routes between origins and destinations (Turrell et al. 2013). It can facilitate alternative routes which may make walking more pleasant or interesting. Areas with high connectivity are characterised by well-connected street networks with numerous intersections, few cul-de-sacs, and small block-sizes (Turrell et al. 2013) (Figure 21).

Figure 21 Comparison of street connectivity showing a) a grid street pattern with high-connectivity and b) low street connectivity



(Source: Thornton et al. 2011)

Measuring street connectivity can be operationalised several ways. One of the more common methods is using the frequency of the number of street intersections with at least three or more turn options within a specified area (Forsyth 2010; Turrell et al. 2013). Another is the number of intersections within the network buffer divided by the total street segment length within that buffer (intersections per km) (Troped et al., 2010) or a comparison of travel distances using a euclidean versus a street network buffer. There is little evidence about which type of measure is most closely associated with walking but essentially these methods are all capturing the 'directness' of possible routes between start and finishing points. Block size is also sometimes used (Grasser et al. 2013; Oakes et al. 2007), whereby larger blocks reflect less connected streets (Oakes et al. 2007), although this measure tends to be used in the US where streets are more uniformly formed around blocks compared with the UK.

Reviews considering connectivity generally concluded that there were positive associations between street connectivity with walking (Grasser et al. 2013; McCormack & Shiell 2011; Sugiyama et al. 2012). However there were differences in outcomes. Grasser et al. (2013) found that neither of the two studies using block size to measure connectivity had any associations with walking for transport whereas all that using intersection density found positive associations. Panter and Jones (2010) reviewed five studies of measuring street connectivity and of these four showed positive associations with with active travel (walking or cycling) and one showed no association. The review of built environment correlates of walking by Saelens & Handy (2008) found equivocal results for relationships between intersection density and walking for transport and recreation. Sugiyama et al. (2012) found street connectivity was significantly associated with utilitarian walking in 58% of the studies examined but for recreational PA in 30% of studies. None of the studies identified in that review assessed street connectivity outside the UK.

Empirical studies found positive associations for a range of physical activity outcomes; walking for transport or active travel (Koohsari et al. 2014; Eriksson 2013; Knuiman et al. 2014; Turrell et al. 2013; Kaczynski 2010; Witten et al. 2012; Badland et al. 2008; Fan et al. 2014), leisure walking and leisure PA (Witten et al. 2012; Sugiyama et al. 2009; Sugiyama et al. 2014), general (Wells & Yang 2008; Witten et al. 2012; Heinrich et al. 2007) and physical activity (Cervero et al. 2009; Heinrich et al. 2007; Duncan et al. 2005; Troped et al. 2010). Strength of associations were often found to be substantial, for example, a US-based study comparing connectivity with likelihood of achieving recommended PA (defined as ≥ 150 min/wk) found that greater street connectivity was linked to a 1.2 to 3.3 greater chance of meeting, compared with not meeting, moderate physical activity guidelines (Odds Ratio = 1.21–3.26) (Heinrich et al. 2007). Turrell et al. (2013) found evidence of a dose-response relationship between increased intersection density (count of the number of four-way or more intersections within each study area) for mid-aged adults in administrative zones in Australia and minutes spent walking for transport, finding increasing odds for likelihood of doing low, medium or high amounts of transport walking compared with no walking with increasing numbers of 4-way intersections. Some studies found connectivity to be one of the most important measures of the BE for supporting PA/walking. Badland (2008), for example, took objective measures of LUM, residential density and street connectivity in Auckland, New Zealand. They found that respondents who commuted through the most connected streets (calculated by dividing the number of street intersection nodes by the number of intersection and cul-de-sac nodes within a 500 m buffer zone of a respondent's commute route) were more likely to engage in transport-related physical activity to access their occupation when compared to those traveling along the least connected (OR=6.9). No associations were found with other BE measures suggesting that connectivity was the most strongly associated with commuting compared with the other meausres. Lee & Moudon (2006) found signficant correlations between 'route' (defined as directness of route) and walking, and concluded this was one of four core constructs defining neighbourhood walkability.

However, other studies found mixed or null effects, for example, Kaczynski (2010) found positive associations between perceived street connectivity with transport PA but not general PA in Ontario, Canada. Ericksson (2013) found weak associations between connectivity with walking for transport and null associations with general walking. Some studies found weaker associations for street connectivity compared with other measures of the BE. For example, in a rare European-based study of street connectivity, Eriksson (2013) compared three measures of the built environment (residential density, street connectivity and LUM) in Sweden, finding weaker associations with walking for street connectivity (number of true intersections per km^2) than residential density and LUM. Glazier et al. (2014) found weaker associations with walking/cycling with street connectivity than for population density, residential density and availability of destinations in their Canadian study. Other authors have suggested that connectivity is likely to be most strongly associated with PA and walking in conjunction with other factors. Koohsari et al. (2014) found significant associations between connectivity (number of true intersections per land area) and transport walking in Adelaide, Australia. They found that this relationship was attenuated after taking availability of destinations into account, availability of destinations accounted for 16% of the total effect of connectivity on transport walking. The authors concluded that associations between connectivity and walking likely to be associated with destinations. Similarly, Geddes and Vaughan (2014) found that route availability is associated with increased walking along routes diverse land uses.

There is a considerable body of evidence demonstrating that street connectivity is supportive of physical activity with walking. There is no fixed metric for measuring connectivity but positive associations with PA were found for different metrics suggesting it is conceptually sound measure of AWP. Some have suggested that more precision of measuring connectivity is required. For example, Ball et al. (2012) used seven measures of connectivity including seven different network connectivity measures which included direction density, intersection density (for 3 or more directions of travel), cul-de-sac density, street density and length density, in their study of associations between street connectivity and BMI in Glasgow (finding null associations). Thus, the mixed evidence may be due to the lack of consistency in measurement of street connectivity or because street connectivity is more likely to be associated with increases in PA when it exists alongside other features of the BE that support PA. The studies reviewed here seem to suggest that there are associations with street connectivity and PA, particularly intersection density. Most evidence of these associations is from the US and Australia; further evidence would be required to determine whether these results may extend to the UK context.

3.2.1.2 Trails

Trails (defined as routes that are open to cyclists and pedestrians but closed to motor traffic) are a functional measure of the built environment that may facilitate physical activity and walking by providing more direct or alternative routes to destinations. They may be perceived as safer, more pleasant and attractive than streets open to vehicles. Consideration of the impact of trails on physcial activity/walking is relatively small in the field of study, with inconclusive results. Huston *et al.*, (2003) found positive associations with presence of trails with leisure PA in the US. Another US study found proximity to trails was associated with transport but not leisure PA (Troped et al. 2003). There is other evidence to suggest that trail use is greater for those living close to trails and that trails set closer to population centres may be better used including evidence from the UK (NICE 2006b) and where these are well maintained (Robert Wood Johnson Foundation 2011). There is some evidence that the availability of trails may increase PA including among people who are not habitually active. Following the opening of a new community trail in West Virginia, US, Gordon et al. (2004) found that among users of the trail, 22.5% were classified as new exercisers who were not habitually active, and 77.5% participants were classified as habitually active exercisers. Nearly all (98%) of the new exercisers reported that their exercise amounts had increased since using the trail and 52% of the habitually active exercisers reported an increase. Other studies have reported less positive results. One study found no significant changes in walking or cycling activities for people living near a newly introduced trail in Sydney (Merom et al. 2003) a finding which has been echoed in a study by Evenson et al. (2005) who found no significant change in leisure activity, leisure activity near home, moderate activity, vigorous activity, and walking for transportation for 366 adults living within 2 miles of a newly opened trail in North Carolina. Rodríguez et al. (2008) examined associations between modifiable features of the BE such as car parking availability, access to transit, neighbourhood traffic, walkways and trails, and sidewalks but found no positive associations between the presence of trails in Maryland, US with transport or leisure walking. Overall, the evidence relating to trails is mixed there is some robust evidence based on experimental study designs to suggest that trials increase physical activity, particularly for those living near to the trail, but other evidence found no associations.

3.1.2.3 Density and sprawl

Measures of urban density and sprawl relate to how compact residences are across land area. Higher density or lower sprawl neighbourhoods are considered to be more supportive of physical activity because there are likely to be proximate to destinations and services (Turrell et al. 2013; Vargo et al. 2012). Higher density may be conducive to perceptions of area safety due to reduced feelings of isolation and greater potential for being seen by other people due to the high concentration of residences (Forsyth et al. 2007). Additionally, traffic congestion also increases with population and employment density, so that at a certain threshold it is more convenient to walk, or walk to the public transport, than to drive (Forsyth et al. 2007). Conversely, lower density areas are considered less conducive to walking due to large tracts of single use land patterns, few destinations, disconnected street networks (such as cul-de-sacs) and monotonous, uninteresting views (Lake and Townshend, 2006). Typically, residential density is measured by taking the number of dwellings per land area, or number of dwellings per residential land use area. Alternatively, measures of 'sprawl' indicate low density housing. Sprawl is more frequently used in the US than in the UK. It can be measured by taking into account features such as population density, percentage living at low and at high densities, area population per square mile of urban land, average block size and percentage of blocks smaller than standard block sizes (Lee et al., 2009).

Reviews by Saelens and Handy (2008), McCormack and Shiell (2011) and Grasser et al. (2013) all found positive associations between density with walking for transport and by Bauman and Bull (2007) with general walking. Weaker or mixed associations were found for walking for leisure (Saelens and Handy, 2008) and active travel (Panter and Jones, 2010) and general walking (McCormack & Shiell 2011). Primary studies found positive for associations between density with PA (Eriksson 2013; Troped et al. 2010; Witten et al. 2012) and walking (Lee et al. 2009; Witten et al. 2012; Sugiyama et al. 2014). Some studies found sizeable increases in PA, Eriksson (2013), for example, found an increases in residential density of 10,000 dwellings per square kilometre was associated with 5.9 more minutes per day of MVPA in a Swedish study. Witten et al. (2012) carried out a study of GIS-measured built environments in New Zealand measuring three BE features and found positive associations with PA for transport, leisure and general walking. Sugiyama et al. (2014) measured perceptions of density in 12 countries across Europe, America, Australasia and Asia, including the UK. The authors measured perceived residential density based on area housing types. The results showed a curvilinear association with residential density and leisure walking, with greater perceived residential density was predictive of higher odds of walking, up to a certain point, with lower odds of walking thereafter. This suggests that there may a threshold for the associations between residential density and leisure walking, and very high residential density may present an unattractive environment for leisure walking. This may be because areas with very high residential density, such as tower block estates have few available destinations or displeasing aesthetics.

Other studies found no significant associations with PA/walking outcomes. In their Australian study, Knuiman et al. (2014) found positive associations between street connectivity, LUM and access to public transit (measured in 1600m street network buffers from participants' homes) but not residential density (calculation not given). In a Brazilian study, Cervero et al. (2009) measured street connectivity, proximity to cycle lanes, density (total of population and employment divided by total square miles) and LUM and found positive associations for street connectivity and proximity to cycle lanes with physical activity but no signification relationship with LUM or density. Badland et al. (2008) found no associations between residential densities (estimated by identifying the meshblocks intersecting the 200m buffer zone of commute route for each respondent, and calculating a weighted average of the population density based on the area of each mesh-block contained within the buffer zone) with likelihood of commuting in their New Zealand study.

There is a lack of clarity about which measure(s) of density have strongest associations with PA. Sometimes population density and residential density are used almost interchangeably. For example, Frank et al. (2010) justify the inclusion of residential density as a measure of walkability based on prior associations found between population density and active travel in previous research by Sallis et al. (2004) and TRB (2005). Moudon et al. (1997) define 'residential density' as number of people, rather than dwellings, per acre (Moudon et al. 1997, p.2). Kent et al. (2011) argue that the conflicting evidence regarding density may indicate that associations arise because of correlations between residential density with other factors that are more likely to influence walking, rather than independent associations. It has also been argued that density is also confused with related terms, such as crowding, or that it is actually a proxy measure for other dimensions such as low-income populations (Forsyth et al. 2007). In order to address some of these issues, Forsyth et al. (2007) compared a variety of measures of density and with 13 different types of walking measures for transport, leisure and walking at work in 400m and 800m Euclidean and straight line buffers around participants' homes in the US. The density measures were:

- Population per unit land area
- Population per developed land area
- Residential population in residential parcels
- Population plus employment per unit land area
- Employment per unit area (Total employees per unit land area)
- Housing units per unit land area
- Lot coverage (Building footprint area divided by area in parcels excluding vacant or agricultural land uses).

The authors found that these measures were associated with the purpose of walking (travel, leisure) but not the amount of overall walking or overall physical activity. No conclusions could be drawn about the relative importance of the different types of density nor the scale at which measures were taken. The authors suggest that density may be a 'zero sum game', whereby in higher density areas people walk more for transport and in lower density areas walk more for leisure.

To summarise, there is considerable evidence of associations between density and PA/walking from diverse countries and continents and including the UK. There is evidence to suggest that residential density is more likely to support transport PA/walking than leisure PA/walking. However, the evidence is mixed. This may be because while density is important for supporting walking, but density alone is not intrinsically appealing. As with connectivity, it is likely to support PA/walking when present in conjunction with other features of the BE such as good connectivity and neighbourhood resources (Kent et al. 2011; Turrell et al. 2013). The unclear findings may also be associated with the lack of consensus about how to measure density (Forsyth et al. 2007).

3.2.2. Destinations measures of the built environment

The presence of destinations may encourage active travel by providing somewhere to travel to, or some types of destinations such as open space or recreation centres may be used for physical activity. The presence and diversity of destinations can also create a more varied and interesting environment in which to participate in PA. The three key dimensions that relate to destinations are proximity, diversity and intensity. Proximity takes account of the distance to destinations. Intensity relates to the number of facilities within a specified area, or the proportion of land use devoted to the amenities. Diversity is the number or proportion of different types of destinations within a specified area. Access to destinations can be measured in several ways. Some studies use a specific type of destination such as greenspace or commercial destinations to assess whether there these specific types of destination are important for supporting PA or walking. Others use a combination of destinations, categorising these into different categories such as commercial, retail and social destinations. It is possible that diverse leisure and utilitarian destinations may encourage more PA by offering a range of activities which may appeal to different people's diverse interests.

3.2.2.1 Access to multiple destinations

Access to a combination of destinations is one of the more frequently measured features of the built environment and positive associations with PA have been found, particularly with walking for transport. The review by Saelens & Handy (2008) found access to destinations had the strongest associations with walking for transport compared with other built environment measures. Sugiyama et al. (2012) found strong evidence of associations between access to destinations and walking for transport. Panter & Jones (2010) found that access to destinations was one of two built environment measures to be consistently associated with active travel (the other was walkability) compared with less consistent results for functional, safety and aesthetic BE measures. Bauman & Bull (2007) found evidence of associations between access to destinations and general walking. Results for recreation walking were mixed. McCormack & Shiell (2011) found positive associations with walking for transport and general walking but little evidence of association with walking for recreation. Similarly, Saelens & Handy (2008) found mixed associations between destinations and recreation walking in contrast to strong results found for transport walking.

Positive associations between access to multiple destinations and walking or active travel were found in empirical studies (Cerin et al. 2007; Glazier et al. 2014; McCormack et al. 2008; Nagel et al. 2008; Nathan et al. 2012; Pikora et al. 2006; Sugiyama et al. 2009; Witten et al. 2012) with null or weaker results for leisure PA/leisure walking (Cerin et al. 2007; Maddison et al. 2009; Pikora et al. 2006; Witten et al. 2012). Destinations were measured differently between studies. For example, Glazier et al. (2008) used a sum of all "retail and service" destinations including public recreation centres and schools in Toronto (Canada). They created neighbourhoods using 800m zones and divided these into quintiles according to their destination index. Between quintile 1 (lowest destinations) and 5 (highest access to destinations) there was an increase of average daily walking/cycling trip per person from 0.10 to 0.28 trips. McCormack et al. (2008) counted presence of transit stations, parks, the river, and beaches in 400 and 1500m neighbourhood zones in Perth (Australia), finding that each additional destination within 400 and 1500m zones resulted in an additional 12 and 11 min/fortnight spent walking for transport, respectively. Witten et al. (2011) developed a Neighbourhood Destinations Accessibility Index (NDAI) to measure access to local destinations in New Zealand. This used a weighted sum of category scores based on presence/absence of access to 31 community service and amenity destinations. These measures were informed by a photo-elicitation exercise asking participants to take and discuss images of `what makes your neighbourhood good and not-so-good for walking?' These were categorised into educational, transport, recreation, social and cultural, food retail financial, health, and other retail destinations. The authors subsequently used the NDAI to compare associations with walking for transport PA, leisure PA and walking. They found strongest associations with walking, for each 1SD increase in NDAI score (OR for any versus no walking =1.44, CI: 1.16-1.79) followed by transport

PA (OR=1.39, CI: 1.15-1.69) and leisure PA (OR=1.27, CI: 1.06-1.53). The associations with walking were stronger than for any other measures used in the study which were Streetscape quality, street connectivity, dwelling density and mixed land use. In particular, this study adjusted for neighbourhood preferences to provide a more convincing causal argument. Cerin et al. (2007) measured perceived access to destinations using the Neighbourhood Environment Walkability Score (NEWS) adapted for an Australian context. In this survey, respondents were asked to rate their environment for access to destinations and ease of walking using the following criteria:

- Can do most of the shopping
- Many shops within easy walking distance
- Many places to go within easy walking distance
- Easy to walk to a public transport stop
- Major barriers to walking
- Footpaths on most of the streets
- Well-maintained footpaths
- Busy streets have pedestrian crossing / traffic signals

They found significant positive associations between perceived access to these destinations walking for transport but not for walking for leisure.

The positive associations found between measures of destinations implies destinations may be important for supporting active travel, particularly walking. However, the diversity of destinations measures used across studies means that it is not clear which destination(s) are the most important for encouraging PA/walking. Studies such as that by McCormack et al. (2008) finding a dose-response relationship between the number of utilitarian destinations in a neighbourhood and time spent walking for transport suggests that multiple destinations are important. However, other studies have found associations with single measures. Ogilvie et al. (2008) carried out a questionnaire for 1322 residents of deprived urban neighbourhoods in Glasgow, Scotland gathering perceptions of socioeconomic status, perceptions of the local environment relating to aesthetics, green space, access to amenities, convenience of routes, traffic, road safety and personal safety, travel behaviour, physical activity and general health and wellbeing using a questionnaire. The only significant associations were found for perceived proximity to shops which showed people had an increased likelihood of having taken part in at least 30 minutes self-reported of travel by walking, cycling per week but there were no reported significant associations with physical activity. Studies by Nagel et al. (2008) and Nathan et al. (2012) illustrate that even when using similar study designs important differences remain. Nagel et al. (2008) used ½ and ¼ mile radius buffers from residents' homes in their sample of older adults (64 years and above) in the US. Their destinations measure was the number and types of retail and catering and community destinations (such as libraries and post offices). There were significantly increased walking times for people living in areas with a higher number of commercial and community establishments in both a 1/4 mile and ½ mile buffers and brisk walking in ½ mile buffers in areas with more commercial and retail establishments. There were no associations between any destinations with likelihood of engaging in any walking. Nathan et al. (2012) used a similar study design and sample group. They measured access to destinations for older adults aged 65-84 years in 400m and 800m distances (equating to the same 1/4 and 1/2 a mile distances used by Nagel et al. (2008) from home addresses in Australia. They classified destinations into slightly different groups from Nagel et al. (2008), measuring food retail, general retail (e.g. newsagent, shopping centre), medical care services, financial services, general services (e.g. hairdresser, pharmacy) and social infrastructure (e.g. cafe, restaurant, place of worship). This study showed different outcomes from those in the study by Nagel et al. (2008). While the study by Nagel et al. (2008) found no associations with likelihood of having walked with access to destinations, Nathan et al. (2012) found adults with access to general services within both buffer sizes, and social infrastructure destinations with 800m buffers were more likely to engage in some, rather than no weekly walking. In contrast to Nagel et al. (2008), they found that access to food retail, general retail, financial services and the mix of commercial destinations within the neighbourhood were all unrelated to likelihood of having walked and that access to medical care services with 400 or 800m buffers reduced the odds of reaching government recommendations for walking (≥150 minutes per week). The incompatible results between these two studies may be partly due to the slight differences in the ways in which destinations were categorised and measured and differences in the walking outcomes considered (although the different locations of the studies may also have contributed to these differences). This comparison serves to highlight the difficulty in drawing firm conclusions about the exact nature of relationships between destinations and PA outcomes as few studies use the same methods and measures. Thus, as with previous BE measures it is difficult to make comparisons between studies to help to understand which type of destinations measure is most likely to support walking. However, there is evidence of strong associations between diverse destinations measures with PA, particularly transport PA/walking.

3.2.2.2 Specific destinations measures

Some of the evidence considers single measures of the BE. Greenspace and PA facilities have been the subject of several studies which are discussed below.

Greenspace

Greenspace can be defined as any vegetated land within urban areas, including parks, gardens, playing fields, woods, grassed areas, cemeteries, allotments, green corridors and vacant land (GreenspaceScotland 2009). Access to greenspace and parks may influence both active travel and leisure physical activity as it provides a throughway to destinations as well as an opportunity for recreation and may be perceived as visually appealing, thereby encouraging people to visit (Troped et al., 2010). Ellaway et al. (2005) found significant evidence of a positive correlation between greenspace and physical activity among adults in their study across several European countries. The authors found that the likelihood of being more physically active was more than three times as high for people living in areas in the highest compared with the lowest quintile for greenery. The NICE review of urban infrastructure found one intervention study in Australia relating to park access and found increased walking following the introduction of a park to a neighbourhood (NICE 2006a). In their Australian study Duncan et al. (2005) found positive associations between distance to parkland and likelihood of achieving recommended PA.

However, generally the literature does not show consistent evidence of positive associations between greenspace with PA outcomes. In their US study, Nagel et al. (2008) measured distance to the nearest park or greenspace from residents' homes in their sample of adults aged over 64 years, finding an inverse association between distance to the nearest park and brisk walking time but not overall walking. Troped et al. (2010) measured area 'greenness' using satellite imaging and found that adults' MVPA was inversely associated with percentage of vegetated ground cover in 1km buffer zones from residences. The authors suggest that these counter-intuitive associations may be due to a strong negative correlation between greenness with other built environment variables included in the study (intersection density, residential population density, housing density and land use mix). They suggest that the relative influence of the greenness may take a subordinate role to density and connectivity. The quality of the greenspace may also be of relevance. Day (2008) found that natural landscapes generally encouraged walking among older adults in Scotland, but poorly maintained parks acted as a deterrent to using these spaces. Ord et al. (2013) considered data on 3679 adults living in urban areas across Scotland with greenspace availability. The authors found no evidence of associations between green space availability with total physical activity, nor activity taking place specifically within greenspace. Wheeler et al. (2015) suggested that part of the inconsistency of associations between greenspace and PA may be due to the treatment of greenspace as a homogenous entity. The authors argue that suggest that the type, quality and context of 'greenspace' should be considered in the assessment of relationships between greenspace and PA.

Leisure facilities

Associations between access to leisure facilities with general PA were generally positive (Bauman & Bull 2007; Heinrich et al. 2007; Hoehner et al. 2005; Boone-Heinonen et al. 2010). Bauman and Bull (2007) found in their review of reviews that proximity to recreation facilities such as sports pitches and areanas recreational facilities and parks significantly associated with increased physical activity but associations with walking and travel PA were very mixed. Boone-Heinonen et al. (2010) measured leisure facility density and physical activity among adolescents in the US and found adolescents took part in increased physical activity in areas with higher concentrations of facilities. There were increasing odds of achieving ≥ 5 bouts of VPA per week with each additional PA facility. Gordon-Larsen et al. (2006) found a dose-response relationship between increasing PA facility and MVPA in 8.05-km buffers around residences in the US. Odds of engaging in ≥ 5 bouts of MVPA increased by 3% in comparison with having no such facilities. Adolescents living in block groups with 7 PA facilities were 26% more likely to be highly active than those with no PA facilities. Relationships between PA facilities and walking were less clear, Salens and Handy's (2008) review found little or no evidence of associations between PA facilities and walking for transport or leisure, which is expected since PA facilities are not primarily used for walking. However, some studies reported positive associations with leisure walking. For example, in their Brazilian study, Hino et al. (2011) found walking during leisure time was associated with having two or more gyms versus none and distance to recreation centres, MVPA was associated with having ≥ 2 gyms vs. none (41.7% vs. 26.0%, POR = 1.5; 95% CI = 1.11–2.1). Bracy et al. (2014) found the number of recreation facilities was consistently positively related to walking for leisure.

3.2.2.3 Land Use Mix (LUM)

Land use mix (LUM) is another concept that relates to access to destinations (Handy et al. 2002). It is a measure of land use diversity within a specified area, thus measuring the proximity and diversity of destinations. Areas with higher LUM are considered a more diverse and interesting environment in which PA can take place. It is typically calculated using an entropy score which takes account of the number and proportion of different land uses. The evidence relating to land use mix and PA is inconsistent. Reviews by Bauman & Bull (2007) and Panter & Jones (2010) report positive associations between LUM and increased PA. Saelens & Handy (2008) found consistent associations between LUM and walking for transport and slightly weaker associations with walking for recreation. Primary studies showed evidence of positive associations with PA (Eriksson 2013; Knuiman et al. 2014; Sugiyama et al. 2014; Troped et al. 2010). For example, Troped et al. (2010) used a LUM measure based on four categories of land use; residential, commercial, recreational and urban public measured in a 1km buffer from residence. They found evidence of increased MVPA taking place in neighbourhood areas with LUM scores (showing similar explanatory effect as intersection density, population density, residential density and greenspace index). Eriksson (2013) found positive associations with LUM and walking for transport in Sweden and in Australia Knuiman et al. (2014) found stronger associations with walking for LUM and street connectivity that for individual destinations or residential density in their longitudinal study of adults. However, there was also considerable evidence showing a lack of positive associations with walking (Cervero et al. 2009; Wells & Yang 2008), active travel (Badland et al. 2008; Kaczynski 2010).

3.2.2.4 Summary

Overall there were some strong associations between access to destinations with walking for transport or general active travel. This evidence includes empirical studies that were based in the UK (Ogilvie et al. 2008; Sugiyama et al. 2009), strengthening the likelihood of these results being applicable in the Scottish context. However, it is difficult to determine which destinations or combinations of destinations are optimal for supporting associations with behaviours since there is a lot of variation in the ways that destinations are measured. Using a validated measure of diverse destinations such as the NDAI may help to address such challenges. Mixed results were found for LUM and PA/walking, and much of the evidence was based outside the UK. Evidence was weak or mixed for associations between greenspace and leisure facilities with walking.

3.2.3 Safety measures of the built environment

Safety related features of the built environment are classified into 'personal' and 'traffic' in the model by Pikora et al. (2003). Measures of personal safety can include perceptions of crime or perceptions of how safe it is to undertake PA. These have not been included in this review since they do not constitute the definition of the built environment used in this review. Infrastructure supporting traffic flow can both improve and diminish feelings of safety. While the presence of high traffic volume streets can enhance perceptions of safety by reducing feelings of isolation, unrestricted traffic can reduce perceptions of safety. The results for associations between neighbourhood safety and PA and walking are mixed, although there is some evidence that worse perceptions of safety are likely to be associated with reduced PA and walking, and improved traffic management may be associated with more PA. While the presence of busy roads has been associated with decreased physical activity (McCormack and Shiell 2011), particularly in children (Bauman & Bull 2007), other evidence has found that the presence of traffic is associated with increases physical activity. Ogilvie et al. (2008) found respondents who perceived there to be a higher volume of traffic were significantly more likely to report physical activity, although the authors suggest that this association may exist because people who are regularly physically active in their neighbourhood are more likely to be aware of high traffic volume. However, Nagel et al. (2008) found a significant association between increased walking time in older adults using a ¼ mile buffer around residences and percentage of high volume streets and fewer minutes walked per week in areas with more low volume streets, which may be due to increases in perceptions of personal safety in neighbourhoods with more traffic due to, for example, less chance of unobserved violent crime. Other studies found no consistent associations with traffic volume and walking (Casagrande et al., 2009; Saelens and Handy, 2008).

3.2.4 Aesthetic measures of the built environment

Aesthetic features may encourage neighbourhood PA by providing more pleasant places to exercise. Some features are considered to enhance an area's aesthetic appeal such as trees, shade and a varied and well-maintained streetscape. Others considered to impact negatively on aesthetics include litter and graffiti. Five of the review studies considered the influence of aesthetics, and of these three reported unclear associations between aesthetic features of the built environment and physical activity participation. This was the case for active transport (Panter & Jones, 2010) general walking (Bauman & Bull, 2007) and walking for transport and recreation (McCormack & Shiell, 2011). However, other evidence suggests such features positively influence physical activity. Saelens & Handy (2008) found positive associations between aesthetic measures and general walking and walking for recreation, but not with walking for transport. The authors reported variable measures of aesthetic features such as cleanliness (Burton et al. 2005), scenery and shade (Cao et al. 2006) and building design, 'attractiveness' and vegetation (Hoehner et al., 2005). Sugiyama et al. (2012) found significant relationships between aesthetic features and walking in approximately one fifth of studies reviewed. Ellaway et al. (2005) carried out a cross sectional survey across eight European countries using objective measures of the environment. They found that in residential environments containing high levels of litter and graffiti, the likelihood of residents being more physically active was approximately 50% lower than in areas with low levels of these incivilities. Overall there seems to be some evidence that some measures of aesthetic features of the built environment may be associated with PA and walking. However, the diversity of measures used and the mixed results reported in several reviews and the lack of evidence relating to different groups limit the conclusions that can be drawn about what type of features are likely to influence PA and for whom.

3.2.5 Walkability

The term 'walkability' refers to how walking friendly an area is (Pak and Verbeke 2013). There is no fixed definition of what constitutes walkability nor how it is measured (Lo 2009). Some studies use measures of 'walkability' to refer to a series of individual measures, others combine these into a single metric. In this thesis, 'walkability' is used to refer to the composite measure. Walkability is considered to have the potential to capture overall AWP. People perceive and experience multiple features of their environment simultaneously (Pak and Verbeke 2013) and decisions about walking are complex and likely to vary according to the purpose and duration of the trip, as well as individual circumstances and preferences. A combined metric is considered to have stronger potential to reflect these multiple facets of perception and decision making than single measures and thus have stronger associations with walking (Vargo et al. 2012). Furthermore, features that support walking are likely to have a stronger influence on behaviour when present in combination with others. For example, destinations would not be accessible without good street connectivity, and likewise good connectivity is less likely to encourage walking unless there are destinations to access, residential density becomes associated with increased walking when combined with other features of a walking-conducive layout, such as proximity to destinations (Filion et al. 2006). Combined walkability metrics can thus account for the importance of the cumulative influence of different facets of the BE on AWP (Kelly et al. 2011).

The study of walkability is a growing area of study. The majority of studies have been published since the early 2000s (Pak & Verbeke 2013). A search of Web of Science academic database for studies with 'walkability' in the title published before 2005 yielded 6 results. From 2005 onwards the same search yields 216 results. One of the earlist walkability indices was developed by Bradshaw (1993). It included wide-ranging objective and subjective measures of population density, presence of off-street parking, availability of benches, the 'chances of meeting someone you know', age at which a child is allowed to walk alone, women's rating of neighbourhood safety, transit 'responsiveness' number of neighbourhood 'places of significance', availability of parkland and presence of pavements. More recent studies tend to focus on either objective or subjective measures of the BE. The following section considers evidence from both these types of walkability and associations with PA and walking.

3.2.5.1 Review of objectively measured walkability

Objective measures of walkability usually use GIS to measure features of the BE over large areas generating data for large sample sizes frequently focussing on functional and destination types of BE features. In their review of reviews, Bauman & Bull (2007) found positive associations between walkability and physical activity and walking. One review found associations between walkability with walking for transport but not recreation (Owen et al. 2004). Saelens & Handy (2008) included 3 studies of objectively measured walkability in their review. One study used a combination of block size and intersection density finding a positive association with likelihood of children walking to school. Two used a combination of residential density, street connectivity, LUM and RFAR both found positive associations, one with walking and one with walking and cycling for transport. Panter & Jones (2010) took evidence from 18 studies concluding that living in more walkable environments is associated with higher levels of reported active travel**.** McCormack & Shiell (2011) reviewed four walkability studies. Two used the same walkability index (intersection density, retail density, retail floor area, and land use mix) finding positive associations with walking for transport but not recreation walking. One also found significant associations with MVPA. One study considered walking for transport only and found positive associations with walkability (combination of commercial floor space, land use mix, residential density, and connectivity). The other study (measuring ease of street crossing, sidewalk continuity, street connectivity, and topography) found positive associations with general walking. Grasser et al. (2013) reviewed four GIS studies of walkability with active travel. One of these comprised housing unit density, entropy index, intersection density and the other three also included retail floor area ratio[1]. All found positive associations with walking and cycling for transport. The strength of the associations varied but was usually substantial. One review concluded that the estimated mean difference between high- and low-walkable neighbourhoods of approximately one to two walk trips per week translates into 1 to 2 km, or about 15 to 30 min more walking per week for each resident of high-walkable neighbourhoods (Saelens et al. 2003).

Associations between GIS measures of walkability from empirical studies also showed overwhelmingly positive associations with walking for transport and active travel (Arvidsson et al. 2012; Bracy et al. 2014; Clark et al. 2014; Frank et al. 2005; Frank et al. 2010; Freeman et al. 2013; Manaugh & El-Geneidy 2011; McCormack et al. 2012; Oluyomi et al. 2014; Reis et al. 2013; Sundquist et al. 2011; Thielman et al. 2015; Van Dyck, Cardon, Deforche, Owen, et al. 2011; Vargo et al. 2012). It was also common for studies to find positive associations with MVPA (Bracy et al. 2014; Frank et al. 2010; King et al. 2011; Oluyomi et al. 2014; Reis et al. 2013; Sundquist et al. 2011; Thielman et al. 2015; Van Dyck, Cardon, Deforche, Owen, et al. 2011). Null or inverse associations with these outcomes were rare, only one study was found reporting negative association between walkability with MVPA (Salvo et al. 2014). There were somewhat weaker results for leisure walking. For example, Sundquist et al.'s (2011) study collected data

[1] Retail floor area ratio (RFAR) is the ratio of retail building to retail land use. A high ratio indicates more land is devoted to building structure, a low ratio is taken to indicate that more of the land is devoted to providing parking space, therefore indicating lower walking potential (Norman et al. 2006).

on 2269 adults aged between 20-65 years living in 32 administrative units in Sweden. They measured LUM, residential density and street connectivity and compared outcomes for people living in high versus low walkability neighbourhoods. In adjusted models, there were 77% higher odds of any walking for active transport and people walked on average 50 minutes more per week than people living in low walkability neighbourhoods. Adults living in highly walkable neighbourhoods took part in 3.1 more minutes MVPA per day, which totals just over 20 minutes per week, almost 15% of the recommended 150 minutes per week. There were associations for recreation walking, but results were weaker, odds of any walking for leisure were 22% higher in high walkability neighbourhoods compared with low walkability, but no significant differences were found in the total amount of time spent walking for leisure. This pattern was also found in other studies such as those by Thielman (2015) who created a walkability score in Canada using destination accessibility, street connectivity, intersection density and block length. Comparing highest to lowest walkability quintiles, covariate adjusted energy expenditure on transport walking was 0.17 kcal/kg/day higher (95% CI, 0.15, 0.18) but there were no significant differences for leisure PA or total PA. Another study by Reis et al. (2013) echoed this pattern of strongest associations between walkability with walking for transport, weaker for MVPA and no associations with leisure walking.

Effect sizes suggest that increases in PA associated with higher walkability scores can contribute towards attaining recommended amounts of PA. Reis et al. (2013) for example, studied walking and MVPA associations with walkability (residential density, intersection density and LUM). They found a 2.10 odds of achieving ≥150 minutes/week transport walking for people living in high walkability compared with low walkability areas (95% CI=1.31, 3.37, p=0.002), and 1.57 increased odds of achieving ≥150 leisure-time MVPA minutes/week (95% CI=1.06, 2.32, p=0.024). Oluyomi et al. (2014) found an increased odds of 1.16 of taking part in ≥150 mins MVPA per week for people in high walkable areas compared with those in low walkable areas. The findings by Sundquist et al. (2011) equates to an increase of over 20 mins MVPA per week for people living in high walkability areas. There was evidence to suggest that there were stronger associations between composite walkability than single measures. Glazier et al. (2014) considered the relative influence of a combination of destinations and residential density on walking in Toronto, Canada. Residential density (calculated as the total number of occupied residential dwellings per square kilometre) and the availability of walkable destinations (calculated as the sum of all "retail and service" destinations) were each significantly associated with active transportation, but the combination of high levels of both measures was significantly associated with the highest levels of walking or bicycling, public transit use and the lowest levels of automobile trips. In their study of 56 US adults, Vargo et al. (2012) considered two walkability indices (described previously) and compared outcomes for individual and composite measures. When testing individual measures, they found population density demonstrated the strongest association with walking trips. However, after accounting for demographic factors, population density was no longer shown to be associated with walking, however, significant associations between the walkability indices with walking persisted. Evidence such as this suggests that composite measures of walkability can be more consistent predictors of walking behaviour than single component measures.

It is difficult to make comparisons about the relative strength of associations between walkability with behaviour outcomes because of key differences between them. A large literature has identified the functional measures of street connectivity and residential density, and the destinations measure land use mix as being imperative for facilitating walking (Turrell et al. 2013; Ewing & Handy 2009) and indices using these measures found positive associations with PA/walking (Frank et al. 2005; Van Dyck, Cardon, Deforche, Owen, et al. 2011; Reis et al. 2013; Sundquist et al. 2011; Oluyomi et al. 2014; Manaugh & El-Geneidy 2011). Van Dyck et al. (2011), for example, found a significant increase of 78.67 minutes per week walking for transport in high walkability areas compared with low walkability areas. Many other studies have used the index developed by Frank et al. (2010) which also includes a measure of Retail Floor Area Ratio (RFAR). These studies create standardised z scores for each component measure and then weight the street connectivity by a factor of 2, because of there is considered to be theoretical and empirical evidence of the importance of this feature (Frank et al. 2010; King & Clarke 2015). Frank et al. (2010) found walking to work was 6% higher for people living in high compared with low walkability neighbourhoods, as well as incremental increases in self-reported walking trips per day for all trip purposes with increases in walkability decile. Bracy et al. (2014) and King & Clarke (2015) found increases of 9.46 minutes travel walking and 31.4 active travel minutes per week respectively and 6.82 and 17.2 minutes per week MVPA high walkable areas. Salvo et al. (2014), however, found a negative association between walkability and MVPA using this index but this type of evidence is extremely rare. Other indices found positive associations with PA using a wider range of features in walkability indices. For example, McCormack et al. (2012) compared self-reported transport and leisure walking for their measure of walkability in Canada which comprised street connectivity, number of businesses, number of bus stops, length of sidewalk, count of different types of parks and recreation facilities, population density, ratio of green to total area, length of path/cycleway, year of region establishment and street pattern. They divided study sites into low, medium and high walkability and found high walkability neighbourhood residents spent 30-min/per week more on neighbourhood-based transportation walking than residents of both low and medium walkability neighbourhoods.

Different methods are used to calculate associations between walkability indices with PA outcomes. Many studies of walkability divide areas into high versus low walkability to maximise variance between exposures to walkability indicators between study groups (Van Dyck et al. 2012). Others have used continuous measures of walkability and still found a consistent incremental increase in PA outcomes as with higher walkability scores. For example, Vargo et al. (2012) compared a composite measure of population density, employment density, destinations, intersections, transit stops and sidewalks with a measure comprising household density, number of retail employees, block area and sidewalks. Respondents who made ≥10% of their home-based trips via walking were classified as 'walkers' versus those who did not ('non-walkers'). The results showed for every unit increase in the composite scores measuring neighbourhood walkability, individuals are 6–10% more likely to be in the walking category. Other studies found incremental increases in PA in relation to walkability (McCormack et al. 2012). This suggests that even small changes in walkability are associated with physical activity behaviour, which adds further to the evidence of walkability as a robust measure of AWP.

Some walkability indices have been weighted, for example the measure by Frank et al. (2010) creates z scores for the measures of intersection density, RFAR, street connectivity and LUM and a weighting of 2 is applied to street connectivity due to theoretical rationale and empirical evidence of the importance of this measure for walking *(ibid).* This walkability metric has been used in several other studies (Van Dyck, Cardon, Deforche, Owen, et al. 2011; King et al. 2011). Sundquist et al. (2011) applied a weighting of 1.5 to street connectivity in their measure which also included LUM and residential density because it comprised only three instead of four measures compared with Frank's measure. Other measures have applied equal weights such as the walkability measure by Freeman et al. (2013) comprising residential density, intersection density, subway stop density, LUM and RFAR. Some studies, however, do not address the issue of weighting (for example, Reis et al. 2013; Bracy et al. 2014; Thielman et al. 2015). Inadequate consideration of weighting weakens measures of walkability index, by inadequate consideration of the relative importance of the component measures (Reid 2008).

A small number of studies have differences in the strength of relationships with PA outcomes for different iterations of walkability indices, to try to augment understandings of which walkability indices are most closely associated with PA outcomes. One such study is that of Manaugh & El-Geneidy (2011) who compared four walkability indices shown in Table 4.

Table 4 Walkability indices compared in the study by Manaugh & El-Geneidy (2011)

Index	Composition
"Walkability index (WI)"	6 x z LUM z Residential density street connectivity
"Walk opportunities"	- Destinations accessibility - intersection index.
'Pedshed'	-Accessibility - land use diversity -public/private realm - natural surveillance -permeability/street connectivity - employment density - number of buildings - number of lots.
'WalkScore'	- Destination accessibility - Street connectivity - Intersection density - Block length

They found that the strongest predictor of walking to shops was the "Walkscore" measure, which comprised destination accessibility, street connectivity, intersection density and block length. The authors also considered the likelihood of walking to school and found in this instance the closest associations were with their "pedshed" measure comprising land use diversity, public/private realm, natural surveillance, permeability/street connectivity, employment density, number of buildings and number of lots. The authors concluded that associations between walkability and walking are likely to vary depending on the purpose of the trip. The results of this study suggest that walkability measures that align with trip purpose are likely to be the most strongly related to walking.

While GIS measures of walkability have the capacity to garner robust evidence based on large sample sizes, some literature critiques such measures for not including detailed measures of the BE (Bopp et al. 2006; Cain et al. 2014). Streetscape audits by trained researchers is one way of collecting microscale environmental information, which can then be correlated with PA behaviour. One such audit tool is the Microscale Audit of Pedestrian Streetscapes (MAPS) measures street design, transit stops, sidewalk qualities, street crossing amenities, and features impacting aesthetics (Cain et al. 2014). This study sought to understand the contribution of streetscapes to explaining physical activity, MAPS audits were conducted along a 0.25 mile route along the street network from participant residences toward the nearest non-residential destination and participants' PA was measured using accelerometers. The authors found that the composite walkability score was related to objective PA in children and older adults.

There are multiple other streetscape audits, such as the Scottish Walkability Assessment Tool (SWAT) (Millington et al. 2009) and the (Pedestrian Environment Data Search tool (PEDS) (Clifton et al. 2007), but evidence comparing such composite walkability measures is more limited than that from GIS measures.

3.2.5.2 Perceptions of walkability

Others argue that it is necessary to incorporate some measure of perceptions into walkability indices (Clifton et al. 2007; Mehta 2008; Pak & Verbeke 2013). There may be differences in associations between perceived and objective measures of the BE with PA because perceptions may mediate engagement with the BE. For example, Ma (2014) found evidence of a mismatch between perceived and objective measures of the built environment with evidence that factors such as factors as sociodemographic attributes, attitudes, social environment, and behaviour could contribute to this mismatch. There is also evidence that objective and perceived environments may have independent associations with PA (Ma 2014; Hoehner et al. 2005). For example, Hoehner et al. (2005) found that, for example, recreational activity was positively associated with perceived but not objective access to recreational facilities. The authors suggest this may be because of varying conditions of the recreational facilities, which is difficult to measure quantitatively. Respondents with neglected or unsafe facilities may not have perceived these as an option for activity, and therefore, these facilities included in the audit assessment may have had little to no effect on physical activity behaviour. In an Australian study, Gebel et al. (2011) collected data on objective and perceived walkability from over 1000 adults in and Australian study. The authors found there was 'fair' overall agreement between objectively measured walkability and perceptions of walkability. However, a minority of respondents (approximately 1/3) determined that they lived in low walkability areas when these were objectively assessed as high walkability and vice versa. Secondly, respondents who perceived high walkability, dwelling density or land use mix as being low decreased their walking for transport significantly more than those with matched perceptions. Those who perceived high walkability, land use mix or retail density as low increased their BMI significantly more than those with concordant perceptions. Thus, perceptions of built environments were independently associated with behaviour outcomes.

An example of a validated measure of perceptions is the NEWS (Neighbourhood Environment Walkability Scale) which includes measures of (1) residential density; (2) land use mix – diversity; (3) land use mix – access; (4) street connectivity; (5)

infrastructure and safety for walking; (6) aesthetics; (7) traffic safety; (8) safety from crime; (9) streets not having many cul-de-sacs; (10) physical barriers to walking; (11) parking difficult in local shopping areas; and (12) hilly streets in the neighbourhood (Cerin et al. 2013). This measure has been associated with positive PA and walking outcomes (Kaczynski 2010; Arvidsson et al. 2012) and there was some evidence of stronger associations with recreation walking that for the GIS measures. For example, Arvidsson et al. (2012) compared outcomes between perceived and objectively measured walkability with physical activity outcomes for 1925 adults in Sweden. Perceived walkability was measured using the NEWS and objective walkability measured street connectivity, LUM and residential density (combined z scores) in 1000m radius around residential addresses. After adjusting for sociodemographic characteristics, high objective neighbourhood walkability was associated with 35.0 (95% CI = 14.6–64.6) and 10.5 (95% CI =5.2 to 28.5) more minutes per week of walking for transportation and leisure, respectively, and 2.8 (95% CI = 0.9–5.0) more minutes per day of MVPA. High perceived neighbourhood walkability was associated with greater increases of 41.5 (95% CI = 15.8–62.9) and 21.8 (95% CI = 2.8–40.0) more minutes per week of walking for transportation and leisure, respectively. It has been suggested that the stronger associations with leisure walking in studies using subjective rather than objective measures of walkability could be due to the incorporation of features relating to aesthetics and safety in the perceptual measures which encourage leisure walking. However, other studies have concluded that aesthetic features are important for both recreation and transport walking (Kaczynski 2010). Some results for associations with perceived walkability were weak, however. For example, one study of a group of African Americans were asked about neighbourhood perceptions. Participants rated the extent to which their neighbourhood was "walkable," if crime was present, and if sidewalks, street lighting, and public parks were present. Responses to each question were dichotomized, and a composite score (higher = more supportive environment) was formed. No significant correlations were found between this composite score with walking or MVPA. There has been considerable work investigating correlations between objectively measured and perceived walkability and the bulk of the evidence suggests that there is high concordance between the two types of measure (Arvidsson et al. 2012; Carr et al. 2010; Leslie et al. 2005). However, there is not enough evidence to conclude whether subjective or objective measures have stronger associations with behavioural outcomes (Leslie et al. 2005). Arvidsson (2012) concluded that both objective and perceived neighbourhood walkability both may be important factors to target in interventions.

3.2.5.3 Walkability evidence summary

Overall, strong associations were found between GIS measures of walkability with walking for transport, active travel and MVPA. These associations were substantial enough to suggest that improved walkability could impact on achieving recommended PA. There was considerable variation in the composition and calculation of walkability but strong associations remained despite differences in study design such as scale of measurement, weighting and sample composition, suggesting that composite walkability measures are a robust estimate of AWP. However, while the diversity of study designs lends strength to the evidence of walkability being an effective measure of AWP, it makes it hard to unpack which measure of walkability is most closely associated with PA behaviour. Associations between GIS measures and walkability were weaker with recreation walking than transport walking, active travel and MVPA. This may be due to the focus on functional and destination features common in GIS measures of walkability and the lack of aesthetic and safety measures. Subjective measures of walkability frequently include more diverse measures and there is evidence that this may strengthen the predictive capacity of walkability with recreation as well as transport walking and MVPA. However, the specifics of which measures are the most strongly associated with PA outcomes remains elusive and there has been little investigation into different iterations of walkability measures to find the most suitable measures. The evidence to date suggests that associations with walkability may vary according to purpose of trip and walkability measures that include a variety of potential BE influences are likely to be the most closely associated with behavioural outcomes.

In general, there is considerable variation in the construction of walkability, making it difficult to ascertain optimal walkability indices (Saelens and Handy, 2008). The International Physical Activity and the Environment Network (IPEN) recommends improved comparability of walkability and has suggested guidelines for international standardised measures of walkability. They recommend the use of and methods for measuring street connectivity, residential density, land use mix and retail floor area ratio (IPEN, 2013). There have also been calls for greater validation of the component measures of walkability (Clark et al. 2014), since there has been little interrogation of the influence of the composite measures or comparison of aggregate walkability compared with its component parts. Future research can address these gaps in research by investigating different iterations of walkability measures and considering the influence of single and component measures. Studies could also include a combination of objective and subjectively defined measures of the BE. Measures should be selected for inclusion based on empirical and theoretical evidence of associations with the behavioural outcome of interest.

3.3 Differential effects of the built environment

The previous sections have discussed the influence of the BE on PA. However, as discussed in Chapter 2, the environment does not determine PA. Rather behaviours are shaped by a culmination of different external and individual factors. A key question in this thesis is whether the influence of the BE is consistent for different demographic and economic groups, such as age, sex, ethnicity and individual socioeconomic status (SES). The following section reviews of the evidence relating to key differences among these groups.

3.3.1 Sex

Some studies have concluded that males and females are influenced differently by different types of built environment. Foster & Giles-Corti (2008) reported in their study of older adults that lower perceived safety was associated with lower physical activity among women but not in men. Boone-Heinonen et al. (2010) found that US male adolescents took part in more physical activity in areas with access to pay physical activities whereas females did not. However, several studies found null associations between different measures of the built environment and PA outcomes. Troped et al.'s (2010) US-based study found positive associations between intersection density, land use mix, population and housing density with adults' MVPA found no significant differences between males and females. Nathan et al. (2012) found positive associations between access to destinations and weekly walking in older adults in Australia with no significant differences between males and females. Freeman et al. (2013) found positive associations of a US-based study of walkability and active travel, with no differences between males and females. Overall, although females have been found to undertake less PA, the evidence does not suggest that there are substantial differences in relationships between built environments and PA outcomes between males and female.

3.3.2 Age

Most of the evidence relating to different adult age groups focusses on older people. Older adults (defined by the World Health Organisation and aged 60 and over (WHO 2003)) may be more likely to experience a range of health-related changes and challenges, such as restrictions in activity (Day 2008). The focus on older adults' relationship with the built environment is important because older adults are one of the least physically active groups (Nathan et al., 2012) and are considered to be likely to be immediate influenced by their neighbourhood since they may have restricted mobility. found that those who reported being less healthy, unemployed or retired were more likely to walk in high density areas than other groups, concluding that the physical activity of these groups is more likely to be affected by the built environment. A review by Foster & Giles-Corti (2008) found after older adults who felt unsafe were more than twice as likely as younger adults to be inactive. Nathan et al. (2012) found positive associations between access to destinations and walking in Australia. They distinguished between different types of services for their sample of adults aged 65 – 84. They found positive associations with walking for general services (e.g. hairdresser, pharmacy) and social infrastructure (e.g. cafe, restaurant, place of worship) and medical services but not for food retail, general retail, financial services, and the mix of commercial destination types. The authors concluded that this result contrasts with positive associations found for younger groups with these types of destinations, arguing that the types of neighbourhood commercial destinations that encourage older adults to walk appear to differ slightly from those reported for adult samples.

This shows there is emerging evidence about differences in relationships between the built environment and walking for older people. However, more research is still needed to consolidate knowledge about the specific types of features of the built environment that can influence older adults' walking (Maddison et al., 2009).

3.3.3 Ethnicity

Evidence relating to ethnicity is limited and mixed. Casagrande et al. (2009) reviewed the evidence from studies which distinguished between African American and white residents in the US but found inconclusive results, as did the review by Foster & Giles-Corti et al. (2008). US evidence suggests that areas with higher proportions of ethnic-minority residence have lower access to PA facilities which was associated with reduced PA (Gordon-Larsen et al. 2006). However, results for other types of built environment features were mixed. Troped et al. (2010) found that population density was positively associated with increased PA for people of white ethnicity but no other ethnicities. Forsyth et al. (2009) found the opposite trend where people of white ethnicity were less physically active overall in high density areas. Freeman et al. (2013) found that associations between lower walkability and reporting zero episodes of active travel significantly stronger for white ethnicity compared with Black and Hispanic groups. However, among those who engaged in active travel, the association between walkability and the number of episodes of active travel did not appear to vary across sociodemographic strata.

No consistent trends were identified associations between the BE and PA for people with different ethnicity, although there is some initial evidence that differences may exist. Furthermore the evidence from empirical studies reviewed is drawn from the US which has a very different ethnic composition from Scotland (where only 3.7% of the population are non-white (ScotStat 2012) compared with 36.3% of the US population (CDC 2010)) and a different urban morphology. As such, this review does not draw conclusions about relationships between the built environment and PA outcomes for people who have different ethnicities in Scotland.

3.3.4 Individual socioeconomic status

There is evidence of different patterns of PA for people who have different socioeconomic status (SES) It is generally found that people with lower SES take part in less leisure and overall PA (Ball et al. 2007; Leadbetter et al. 2014; Cerin et al. 2009; Pliakas et al. 2014; Taylor et al. 2006) but more occupational PA (Leadbetter et al. 2014) and occupational walking (Pliakas et al. 2014) and walking for transport (Cerin et al. 2009; Manaugh & El-Geneidy 2011). It has been argued that people with low SES are disproportionately influenced by their immediate environment because they are likely to be more constrained by lack of transportation and opportunities for mobility (Papas et al. 2007). As such it is particularly important to understand the role of the BE in supporting PA/walking to try to understand the role of the BE in such inequalities.

A study of US adults found that the association between education and physical activity is mediated by perceived neighbourhood walkability and safety (Pratt et al. 2015), suggesting that interventions focused on enhancing walkability and safety could reduce the disparity in physical activity associated with education level. Some studies found positive associations between the BE with walking found no significant differences by individual SES (Forsyth et al. 2009; Freeman et al. 2013; Sundquist et al. 2011), suggesting that the positive relationship between BE and walking was consistent across groups. A US study by Manaugh & El-Geneidy (2011) found that respondents living in higher income households were more sensitive to area walkability than those in low income households, the authors suggested that this is because the people living in lower income households were less likely to have a choice about their mode of transport and had no choice but to walk regardless of the quality of their environment.

In general, it appears that relationships between the BE and PA and walking may be fairly consistent across SES groups. There is evidence that people who have lower SES walk more and so a supportive environment is likely to be particularly important among this group.

3.4 Area inequalities

This section will summarise summarising trends in differences in the amount or type of PA that people do in areas with different SES and discrepancies in the relationship between the BE and PA by area socioeconomic status (SES).

There is a well-documented inverse relationship between area deprivation and physical activity. People living in areas with higher deprivation take part in less PA overall (Giles-Corti, 2002; Kavanagh et al., 2005; Reis et al., 2013; Spence & Lee, 2003; Stafford et al., 2007). The results of the 2012 Scottish Health Survey (SHeS), for example, showed that as area SES increases, so does the proportion of adults reaching recommended physical activity levels. Nearly 80% of those in the least deprived quintile reached the recommended physical activity level compared to just over 54% in the most deprived quintile (Leadbetter et al. 2014). There is evidence of an independent association between area deprivation with physical actvity with inequalities in outcomes remaining after adjusting for individual SES (Kavanagh et al. 2005). However, associations with walking or transport PA appear show the opposite trend, with lower area SES associated with increases in walking or active travel (Turrell et al. 2013; Giles-Corti 2002; Goodman 2013; Van Dyck et al. 2010; Pearce & Maddison 2011; Stafford et al. 2007).

The reasons for lower overall PA in places with higher deprivation may be driven by different access to resources. Some research has suggested that area deprivation is associated with lack of pysical activity resources (Estabrooks et al. 2003; Taylor et al. 2006), which might discourage PA in areas with lower SES. Macintyre et al. (2007) found more community health clinics, general practices, dentists, opticians, and pharmacies in the richer compared to poorer neighbourhoods in Scotland. However, other evidence points to an equal; or even greater access to recreation and greenspace facilities in more deprived areas. Macintyre et al. (2007) reported greater access to recreation facilities and greenspace in more deprived areas in Scotland. Ellaway et al. (2007) found that there was a higher density of children's play areas in more deprived areas of Glasgow, Scotland. Ogilvie et al. (2011) and found that the number of recreation facilities available within 10, 20 and 30 min walking and cycling thresholds in Scotland was significantly lower in the most affluent areas.

It is possible that there are characteristics of higher deprivation neighbourhoods that discourage PA. For example, there is some evidence that resources in areas with lower SES are of worse quality. Badland et al. (2010) found availability of Public Open Spaces (POS) did not vary by neighbourhood deprivation in a study based in New Zealand, but found that the quality of the POS may differ by neighbourhood level SES. Jones et al. (2009) found the accessibility of greenspaces in England was better in more deprived areas but those residents had more negative perceptions and were less likely to use the greenspaces. The authors suggested that interventions to improve PA among residents in low SES areas should target the perceptions and needs of residents of deprived neighbourhoods (Jones et al., 2009). Other work has found that while areas with lower SES may have BE that are supportive of pedestrian activity, there may be social, safety and aesthetic factors that detract from these features (Freeman et al. 2013; Cerin et al. 2009) and as such suggest that creating greener, more aesthetically pleasing environments may help to reduce SES inequalities in participation in physical activity.

The reasons for higher walking for transport or active travel in more deprived neighbourhoods could be due to better availability of resources or might be due to restrictions on behaviours. Turrell et al. (2013), for example, found that higher levels of walking for transport in disadvantaged neighbourhoods was partly due to both living in a built environment more conducive to walking and residents having more limited access to a motor vehicles (Freeman et al. 2013). Some of the evidence reported stronger associations between built environment resources and positive PA outcomes in areas with higher SES (Eriksson 2013; Fan et al. 2014; Freeman et al. 2013; Witten et al. 2012). This type of outcome suggests that people living in areas with high SES are more likely to be influenced by changes in the BE. However, other studies tested for interactions in relationships between the BE and PA finding that relationships were consistent in areas with different SES (Reis et al. 2013; Sundquist et al. 2011; Van Dyck et al. 2010) for example, Sundquist et al. (2011) and found positive associations between walkability and walking outcomes in Sweden with no significant differences between areas with different aggregate income levels of deprivation.

It is important to understand the reasons for lower PA outcomes in more deprived areas so that inequalities in PA behaviours can be tackled. Improvements to the BE may be one mechanism through which PA can be supported, which may help to ameliorate inequalities in PA outcomes, particularly through active transport.

3.5 Methodological issues in research into relationships between the built environment and physical activity

3.5.1 Study design

Many of the studies relating the built environment and physical activity adopted a cross sectional design. (Cutts et al. 2009; Ellaway et al. 2005; Gordon-Larsen et al. 2006; Nagel et al. 2008; Troped et al. 2010). There have been calls for more work using experimental designs to research (Bauman & Bull 2007; Lee et al. 2009; NICE 2008). One of the main criticisms of cross sectional studies is that they cannot account for a 'self-selection bias', in that residents who are more physically active may choose to live in areas that have built environments that are conducive to physical activity. There is limited evidence on the likelihood of such a self-selection bias and the results are mixed. Boone-Heinonen et al. (2010) used a longitudinal study design to measure relationships between the built environment and physical activity, taking into account those who moved and those who did not to test for any self-selection bias. The authors concluded that residential self-selection was not generally a confounder in associations between the BE and PA. In a study in New Zealand, Witten et al. (2012) asked respondents about preferences for living in a more walkable or less walkable neighbourhood and included this preference as a covariate in their analysis of associations between the built environment and physical activity to account for potential self-selection bias. The authors found positive associations between BE and PA persisted. A study in New Zealand by (Ivory, Blakely, et al. 2015) tested associations between features of the BE (destination density, street connectivity, area attractiveness) for interactions with factors that were proxies for greater exposure to the residential neighbourhood environments (such as lack of car ownership and not working full time). The found significantly increased positive associations between the BE and PA for groups hypothesized to spend more time in their neighbourhood environment, which strengthens the evidence of a causal association between the BE and PA. A number of reviews concluded that associations between the built environment and physical activity are likely to exist independently of residential location choices (McCormack & Shiell 2011; Panter & Jones 2010; Van Dyck, Cardon, Deforche, Owen, et al. 2011).

Conversely, Lee et al. (2009) compared the results of a cross sectional analysis of the relationship between urban sprawl and physical activity among men in the US in 1993 and 1998 and longitudinal associations between changes in exposure to urban sprawl for those in the sample who moved to different areas and physical activity between 1993 and 1998. The cross-sectional analysis showed a significant association between less sprawl and more walking but the longitudinal analysis found no difference between overall physical activity between the men who moved to more sprawling or less sprawling areas and those who remained at the same level of sprawl. Nor were there any significant changes in walking between the groups. Overall there is mixed evidence about whether self-selection plays a role in associations between the BE and PA. This is a key limitation of cross sectional study designs that are frequently used in research in this field. However, some studies have accounted for this in their study designs and found that associations remain even after accounting for the role of self-selection in neighbourhood of residence.

3.5.2 Exposure scales

Scales of exposure varied considerably between studies. Some studies used administrative units as neighbourhood exposure measures (Freeman et al. 2013; Gordon-Larsen et al. 2006; Sundquist et al. 2011) and others use buffer zones around residences (Berke et al. 2007; Nagel et al. 2008). Some administrative units are considered to form naturally occurring neighbourhoods, for example, Sundquist et al.'s (2011) study used administrative districts that follow street networks and have similar types of buildings thus making them relatively homogenous and natural spaces for active travel. Others use administrative units without an explicit rationale. Buffer zone sizes varied between studies, and some use a Euclidean buffer and others a street network buffer. Cummins et al. (2007) argue that such exposure scales are often chosen without theoretical or empirical justification. As such, true causally relevant geographic context is not known (Diez Roux & Mair 2010). These issues relate to the Modifiable Areal Unit Problem (MAUP) (Flowerdew & Martin 2005) which concerns the problem that in analysis of aggregate spatial data, the conclusions reached might be dependent upon the definition of the spatial unit for which data are reported. There have been calls for further research and better theoretical reasoning to ascertain the most appropriate exposure scales in this type of research (Kwan 2012). Some studies took steps to improve evidence about different exposure scales, for example, Nagel et al. (2008) and Nathan et al. (2012) used two buffer zones in their studies and compared results for relationships between built environment measures and walking within each. However, overall, there is little agreement between studies about the scale of exposure or exploration of the most appropriate scale making it impossible to discern at what scale built environments might influence physical activity.

3.5.3 Measures of physical activity

The influence of different types of environment on different types of physical activity can be obfuscated by non-specific outcome measures. For example, studies have found a cross sectional correlation between proximity to leisure facilities and amount of physical activity (Boone-Heinonen et al., 2010) (Gordon-Larsen et al., 2006), but did not ask respondents to specify what type of physical activity or where their physical activity took place. Therefore, it is not possible to discern whether there was more physical activity carried out that took place within or travelling to, leisure facilities, or whether this correlation was incidental. Handy et al. (2002) suggest more work is needed to identify the characteristics of the built environment that should be measured and explore more appropriate ways of measuring them. (Giles-Corti, Timperio, et al. 2005) criticize the use of generalised 'physical activity' or 'walking' outcome measures in studies of walkability, arguing that these should be specific, for example, research looking at the relationship between neighbourhoods and walking should specifically seek to find out about walking that takes place in the neighbourhood.

3.5.4 Location of research

The majority of research into the built environment and physical activity has been carried out in the US (Bauman & Bull 2007). This is a limitation of the evidence since it may not be reasonable to assume that factors are replicable in other areas because of differences in urban form, and there have been calls for greater UK based research (Bauman & Bull 2007; NICE 2008). In particular, urban areas in the US and Australia were developed in conjunction with the increased use of motor vehicles, whereas European and UK cities developed prior to this, which may result in important differences in urban environments. Key differences include, for example, lower residential densities outside the UK. In Australia, residential densities of 8–10 dwellings/hectare are common, and in the US this drops to 5 dwellings/hectare; however, in the UK standard suburban development is around 25 dwellings/hectare (Townshend & Lake 2009). An absence of pavements in countries such as the US and Australia which may decrease walking potential whereas in the UK provision of pavements in residential urban areas is almost 100 per cent (Townshend & Lake 2009). The US has particularly low access to public transport making comparisons of high/low transit density between countries invalid (Sallis et al., 2009). There may also be important differences in behaviours between countries. For example, a study by Sugiyama et al. (2014) examined between-country differences in walking. They found that participants in some European countries (the Czech Republic, Denmark, and Spain) tended to walk more often and longer for recreation, and to report better environmental perceptions. In contrast, Latin American countries (Brazil, Colombia, and Mexico) were lower in the walking frequency, duration, and some environmental attributes.

3.6 Summary; implications for research into built environments and walking in Scotland

This review has shown that there is evidence of associations between built environment measures and walking, and that much of this evidence is likely to be significant in a Scottish context. Access to destinations, walkability, street connectivity, density and to a slightly lesser extent aesthetics and safety measures were all associated. There were key differences in relationships between influences on travel and leisure walking, with destinations and walkability being more frequently associated with walking for transport and safety and aesthetics with walking for leisure. There is a lack of consistency of methods used to take measures of the built environment which limits the potential for making comparisons between studies and there is still ambiguity about precise features of the built environment that are associated with walking, and at what spatial scales these influences operate.

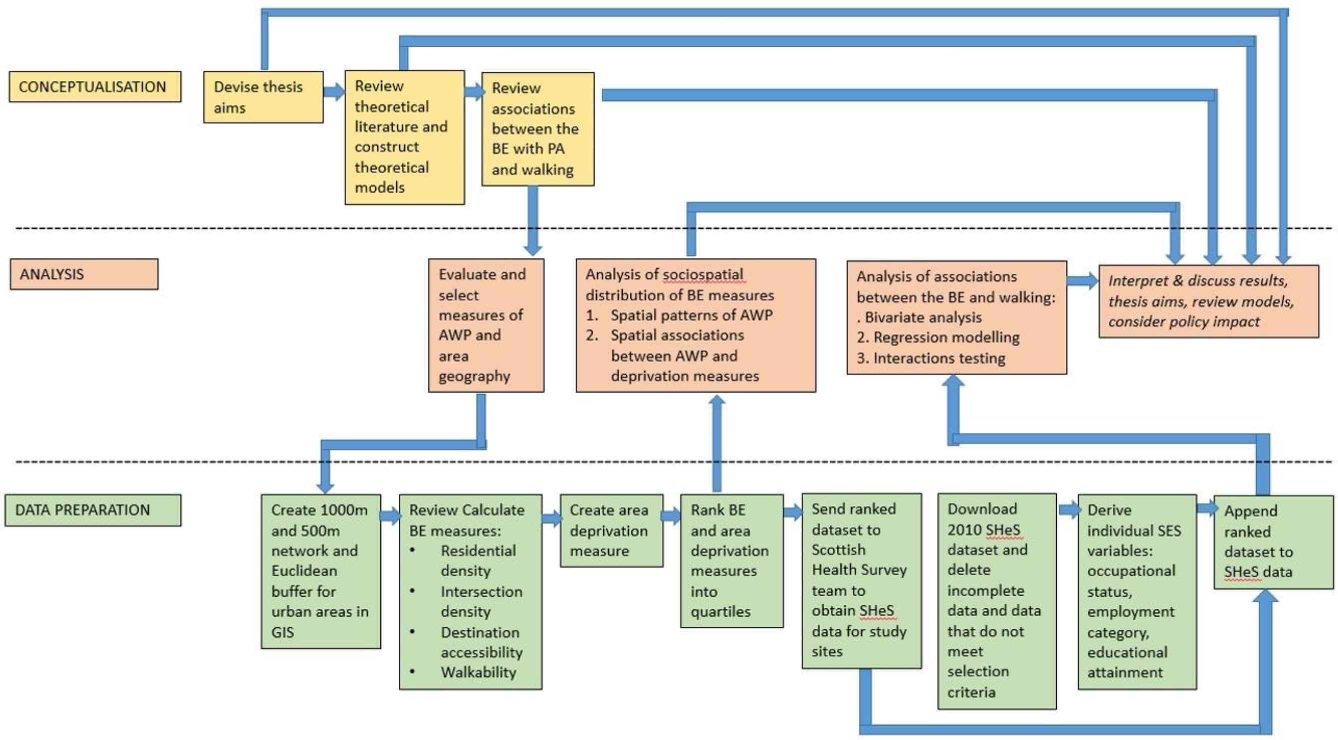
There is emerging evidence of inequalities in relationships between the built environment and walking for groups such as older adults or in areas with different levels of deprivation. However, there is a lack of consistent evidence and it has been recommended that further research should be carried out to clarify differences in associations for different people and in different types of areas. There is a lack of evidence from the UK and Scottish context, and it is recommended that research should be carried out in these places.

Chapter 4. Methodology

4.1 Introduction

Drawing on the reviews of conceptual models (Chapter 2) and review of the empirical literature on relationships between the built environment (BE) and physical activity (Chapter 3), this chapter describes the methodology used to achieve the aims of the thesis. The overall methodology used in this research is depicted in Figure 22.

Figure 22 Thesis methodology diagram



The conceptualisation stage of the thesis has been carried out in previous chapters. This chapter will start at the initial analysis stage. The first sections introduce the selection of neighbourhood study sites, four built environment measures and a measure of area deprivation. This is followed by a description of the analytical strategy employed for analysing the distribution of the built environment measures across urban Scotland. The subsequent section describes the data preparation and then analytical strategy for investigating relationships between the built environment and walking behaviours for residents in urban Scotland.

4.2 Devising and calculating study sites

The geographic unit used to measure exposure to AWP should reflect the neighbourhood area in which people walk daily. Typically, neighbourhood area is measured in one of three ways, administrative areas, parcels of residence or buffer zones around specified points. A summary of these is shown in Table 5.

Table 5 Comparison of types of small area geographies

Geography	Description	Advantages	Disadvantages
1.Administrative area	An area with administratively defined borders, such as a Local Authority District	Data are readily available in the form of census administrative units, making the data processing and analysis phase easier	This is an arbitrary unit and there is no rationale for the boundary from a walking perspective
2. Parcel of residence	A selection of small contiguous units, such as clusters of postcode units, with similar built environment characteristics	Groups neighbourhoods with similar characteristics so that built environment measures for the area are applicable to all the units contained within the cluster.	Analysing and selecting contiguous parcels with similar characteristics across the Scotland would be a large data processing task. Boundaries of such parcels are arbitrary from the perspective of walking distances from residences.
3. Buffer zones	A buffer is drawn around a centroid point. Buffers can be either Euclidian or network types.	Captures the features surrounding a centroid and not restricted to artificial boundaries. Less arbitrary than administrative areas as based around the distance that people typically walk from their home.	Other data not available for these geographies.

The first option in Table 5 is administrative units. These are pre-existing units of land, usually delimiting municipal boundaries. These are readily available for use in research as they are freely available for download. However, administrative units do not necessarily reflect likely walking environments. Their use may obscure relationships between built environments and walking because they do not reflect the true scale of associations (Lee & Moudon 2004; Riva et al. 2009). As such, this option could lead to a mismatch between neighbourhood exposure and walking and was rejected for this

Buffer zones based around residential centroids were selected for use in this research, this is shown as option 3 in Table 5. A buffer zone is a land area drawn around a centroid at a specified distance. Buffer zones are flexible measures that can be created using theoretical and empirical rationale of likely walking zone size so can more accurately reflect people's experience of their neighbourhood walking environment than pre-defined geographical units.

The use of buffers is supported by a number of publications which have found positive associations between measures of the built environment and walking using buffer zones around residences (Pikora et al. 2006; Nathan et al. 2012; Nagel et al. 2008; McCormack et al. 2012; Berke et al. 2007). The use of buffer zones is also recommended by the International Physical Activity and the Environment Network's (IPEN) guidelines for internationally standardised measures of walkability (IPEN 2013). Some authors have noted that people are not necessarily influenced by the spaces that are near to their homes. Perchoux *et al.*, (2016) observe that since people are mobile they are exposed to a variety of environments and AWP outside the residential environment may differ from exposure with the residential environment. Studies accounting for exposure beyond the residential neighbourhood have used multiple locations for daily visited activity spaces. The use of fixed areas of exposure in residential neighbourhoods is thus considered to weaken our understanding of potential links between environments and physical activity behaviour. However, (Chaix et al., 2013) reason that for physical activity research this would only elucidate where people exercise would only serve to show what types of places people use to take part in physical activity, the direction of causation (whether these places engender physical activity, or whether people go to these types of places in order to take part in physical activity) is no clearer. The focus of this research was to explore associations between residential environments and walking and therefore the use of a neighbourhood exposure is appropriate and means that the outcomes can be considered of direct consequence to policies aimed at shaping residential environments.

A disadvantage of the neighbourhood buffer measure is that for the purposes of this study data from the Scottish Health Survey (SHeS) was needed. SHeS data is only available for pre-defined administrative units such as postcode units or Output Area and so there will be a slight mismatch between these datasets.

Buffer centroids

Buffer zones are created around buffer centroids. The centroids should reflect the centre of people's neighbourhood walking area, or 'activity space'. Using individual household address points would be a useful centroid to use since the purpose of this study is to understand walking within local residential neighbourhoods. However, these data were not available in this research to protect respondent confidentiality (see Section 4.8). Therefore, it was necessary to use centroids of aggregate geographies to create the buffers. Three alternatives were considered for use as the buffer centroid, a comparison of these is shown in Table 6. Smaller geographic units contain fewer residences and so reflect individual address points. Initially, postcode unit centroids were selected because these are the smallest geographic area for which the Scottish Health Survey data are available, and contain an average of only 15 residences. However, the huge number of centroids involved made this unfeasible using Arc GIS. Instead, Output Area (OA) centroids were selected. OAs are the next smallest geographic unit available in Scotland, containing an average of 50 addresses and are the next smallest geography available after postcode units. OA centroids are population weighted, with the centroid at the centre of the spatial distribution of the population, rather than the geographic centre of the OA. This means that buffer zones created around OA centroids capture the neighbourhood area of the most densely populated parts of each OA. This means that the buffer zone would capture the most densely populated part of the OA and so be the closed match with individual data from the SHeS.

Table 6 Comparison of potential neighbourhood buffer zone centroids

Data	Details	Advantages	Disadvantages
Household	Individual household used as centroid of buffer zone.	Closest match to individual activity space around the home.	Not possible to obtain necessary data from the Scottish Health survey due to data confidentiality restrictions.
Postcode unit	Approximately 140,000 postcode units in Scotland containing approximately 15 addresses each.	Smallest available land units in Scotland for which data from the Scottish Health Survey are available. Using the smallest administrative zones available would result in closed approximation to activity zones drawn around individual households	Resulted in data processing issues due to the large numbers of postcode units.
Output Area (OA) centroids	42,604 output areas in Scotland. Target OA size is 50 households, but range from 20 to 50 households. Formed from clusters of adjacent unit postcodes. Designed to have similar population sizes and urban/rural status.	OA centroids are population weighted so select points with the highest population concentration avoiding large unpopulated areas. Smaller geography than Datazones.	Larger and therefore less precise than postcode units.
Datazone	6,505 Datazones in Scotland with populations of between 500 and 1,000 household residents. Respect physical boundaries and natural communities. Contain households with similar social characteristics.	Datazone centroids are population weighted so select points with the highest population concentration avoiding large unpopulated areas.	Larger geography than postcode units or OAs.

Buffers can be created using straight line distances from a centroid (Euclidean) or use distances measured along street networks (network buffers). Network buffers are measured using distances along street networks and therefore more accurately reflect pedestrian experiences within the buffer than those drawn using a Euclidean buffer. Euclidean buffers can potentially reflect areas that are inaccessible to pedestrians, for example over train tracks. Therefore, network buffers were selected for use in this research with one exception (see section 4.3.2).

Size of buffer zone

Buffer zones should reflect typical walking activity spaces. Typically, studies of walking behaviour use buffer zones of between 400-1600m to reflect anticipated neighbourhood walking zones and thus exposure to built environment features through walking. Buffers should be able to capture walking to meet recommended PA target (a least a continuous walk of at least ten minutes) since this is a key outcome of the research. To meet these requirements, a 1000m (1km) buffer zone was selected. 1km is considered the maximum distance that people are likely to walk in their neighbourhood to run errands or when taking a stroll for leisure and has been used in numerous other studies (for example, Berke et al. 2007; Frank et al. 2005; Lee & Moudon 2006; Salvo et al. 2014). 1km is also considered to be large enough to capture a continuous walk of 10 minutes (McCormack et al., 2012) required to meet national PA targets. It is likely that typical activity spaces differ between individuals. There may be some groups such as older adults or those with young children, who may stay closer to home than other groups (Chaix et al. 2013). Chapter 3 identified a gap in evidence evaluating the impact of different exposure zones in the strength of associations between the built environment (BE) and PA. To address these issues, an additional smaller buffer of 500m was used. This size is frequently used within other relevant literature (for example Bracy et al. 2014; Salvo et al. 2014). The 500m zone serves as a comparison with the 1000m zone to show whether associations are stronger within a smaller exposure scale for potentially less mobile people such as older adults. This may show implications for policy decisions about how to improve walking environments for different groups. These buffer zone sizes are also recommended by the IPEN network which aims to bring together research methods to facilitate joint analysis of data and so these buffer zones increase the potential for the results to be comparable with other studies.

The following section details the methods used to create the 500m and 1000m network and Euclidean buffer zones around output area centroids across urban Scotland. There were three types of dataset required for this process, Scotland's urban/rural classification, streets and paths data, and output area boundaries. The datasets used in the creation of the small area geographies are shown in Table 7.

Table 7 Data used for creating small area geographies

Data		**Data source**	**Details**
Urban/rural classification data		Scottish Neighbourhood statistics http://www.sns.gov.uk/	Used to identify and select the most urbanised places in Scotland to use in the study.
Output Area (OA) boundaries and output area centroids, 2001		Scottish Neighbourhood statistics http://www.sns.gov.uk/	Includes geographic area and population weighted centroid. Used as the centre of the buffer zone area
Roads data	Integrated Transport Network (ITN) layer	Ordnance Survey Mastermap data (via Edina)	Road network.
	Urban paths (UP)	OS (via request)	Paths suitable for non-vehicular users including pedestrians, cyclists and wheelchair users.
Scottish settlements		Register Office for Scotland	Contains unique settlement code used to link OAs to settlement locations.

To create the small area geographies to form the neighbourhood areas for this study, buffer zones were created around Output Area (OA) centroids. The OA boundaries and population weighted centroids dataset shapefile were sourced from the Scottish Neighbourhood Statistics website. There were 42,604 OAs in Scotland based on the 2001 OA dataset which was the most recent available at the time the work was carried out. This study focuses on urban areas of Scotland and so it was necessary to identify which OAs lay in urban Scotland. The Scottish Government publishes an urban/rural classification, which ranks OAs by size and their position in relation to other settlements. The classifications are summarised in Table 8.

Table 8 Scottish Government Urban Rural classification

Classification	Description
1 Large Urban Areas	Settlements of over 125,000 people.
2 Other Urban Areas	Settlements of 10,000 to 125,000 people.
3 Accessible Small Towns	Settlements of between 3,000 and 10,000 people and within 30 minute drive of a settlement of 10,000 or more.
4 Remote Small Towns	Settlements of between 3,000 and 10,000 people and with a drive time of over 30 minutes to a settlement of 10,000 or more.
5 Accessible Rural	Settlements of less than 3,000 people and within 30 minutes' drive of a settlement of 10,000 or more.
6 Remote Rural	Settlements of less than 3,000 people and with a drive time of over 30 minutes to a settlement of 10,000 or more.

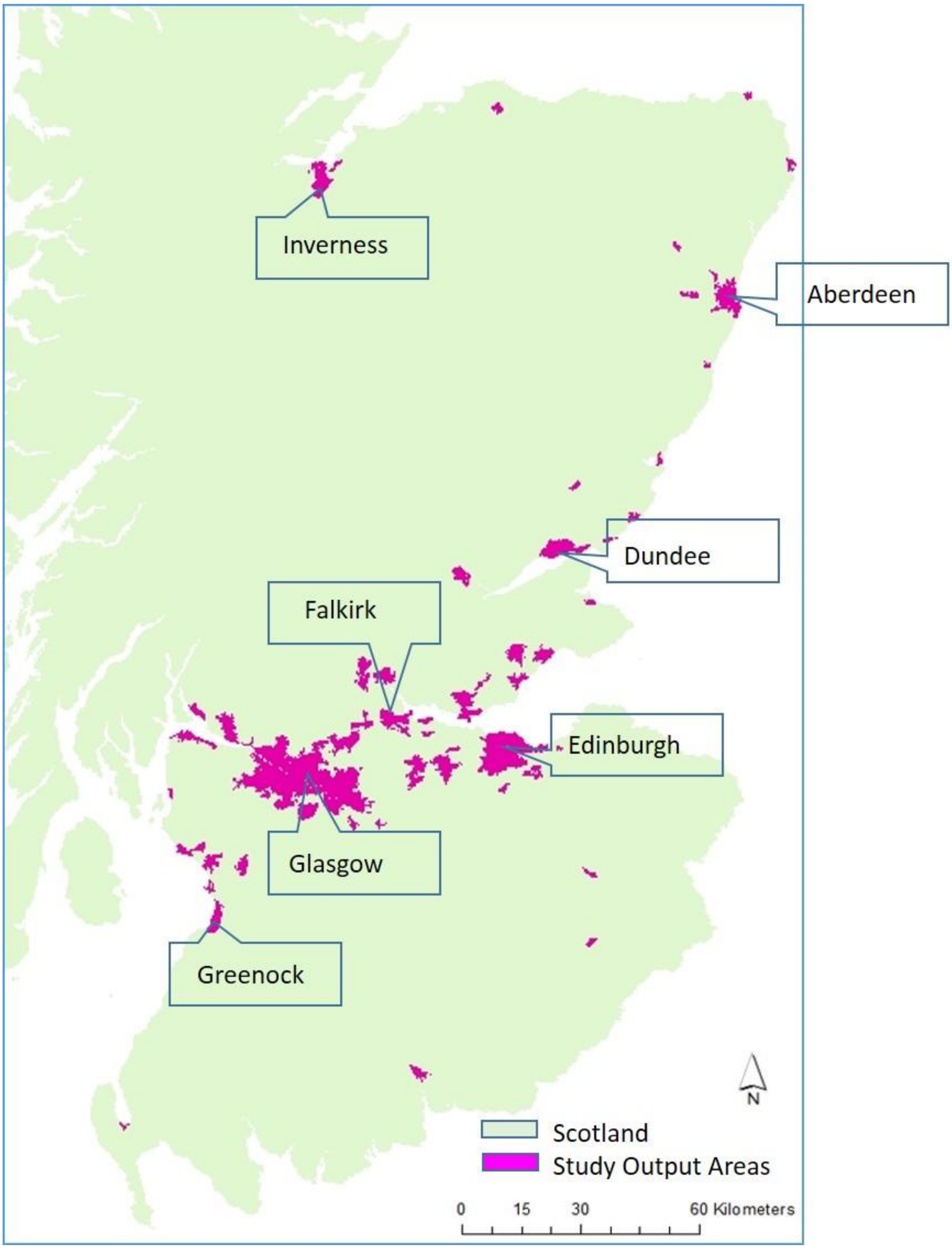
(Source: The Scottish Government 2010)

OAs classified as urban/rural rank 1 and 2 were selected because these urban areas were compatible with the datasets required to create the built environment measure discussed in Section 4.3.2. This resulting sample of 30,066 OAs (70.6% of all OAs) were linked to data on Scottish settlements obtained from the General Register Office for Scotland. Table 9 shows the list of settlements included in this study and the numbers of OAs within each. Most of these lie across the central belt of the country that includes Glasgow and Edinburgh. These two settlements contained almost half of all urban OAs, followed by Aberdeen and Dundee, which reflects the high level of urbanisation in these areas. None of the OAs lay in the Islands due to these being smaller settlements. Figure 23 shows a map of the 30,066 OAs.

Table 9 Scottish settlements into which the 30,066 study Output Areas fall

Settlement	**count of OAs**						
Glasgow	10,021		Inverkeithing | Dalgety Bay	228		Linlithgow	96
Edinburgh	4,024		Buckhaven	216		Fraserburgh	96
Aberdeen	1,745		Alloa	204		Stranraer	95
Dundee	1,364		Arbroath	198		Carnoustie	88
Falkirk	782		Elgin	172		Inverurie	85
Greenock	639		Cowdenbeath	158		Whitburn	84
East Kilbride	590		Bonnybridge	152		Armadale	80
Blantyre | Hamilton	531		Peterhead	148		Stonehaven	75
Ayr | Prestwick	529		Larkhall	141		Tranent	73
Livingston	430		Hawick	139		Westhill (Aberdeenshire)	66
Kirkcaldy	407		Helensburgh	136		Culloden	57
Perth	382		Kilwinning	131		Kennoway	53
Dumbarton	380		Erskine	125		Blackburn (West Lothian)	41
Kilmarnock	377		Bathgate	124		Hallglen	27
Inverness	376		Galashiels	123		Banknock | Haggs	24
Stirling	372		Troon	120		Halbeath | Crossgates	21
Cumbernauld	371		Boness	119		Thornton	17
Glenrothes	364		Forfar	117		Plains	15
Dunfermline	332		Penicuik	113		Blackwood (Cumbernauld)	13
Dalkeith	318		St Andrews	110		Bilston	10
Irvine	299		Montrose	110		Carmunnock	9
Dumfries	265		Broxburn	109		East Whitburn	8
Ardrossan	263		Carluke	103		Hawkhead	7
Kirkintilloch | Lenzie	236		Largs	99		Other	134
						Total:	30,066

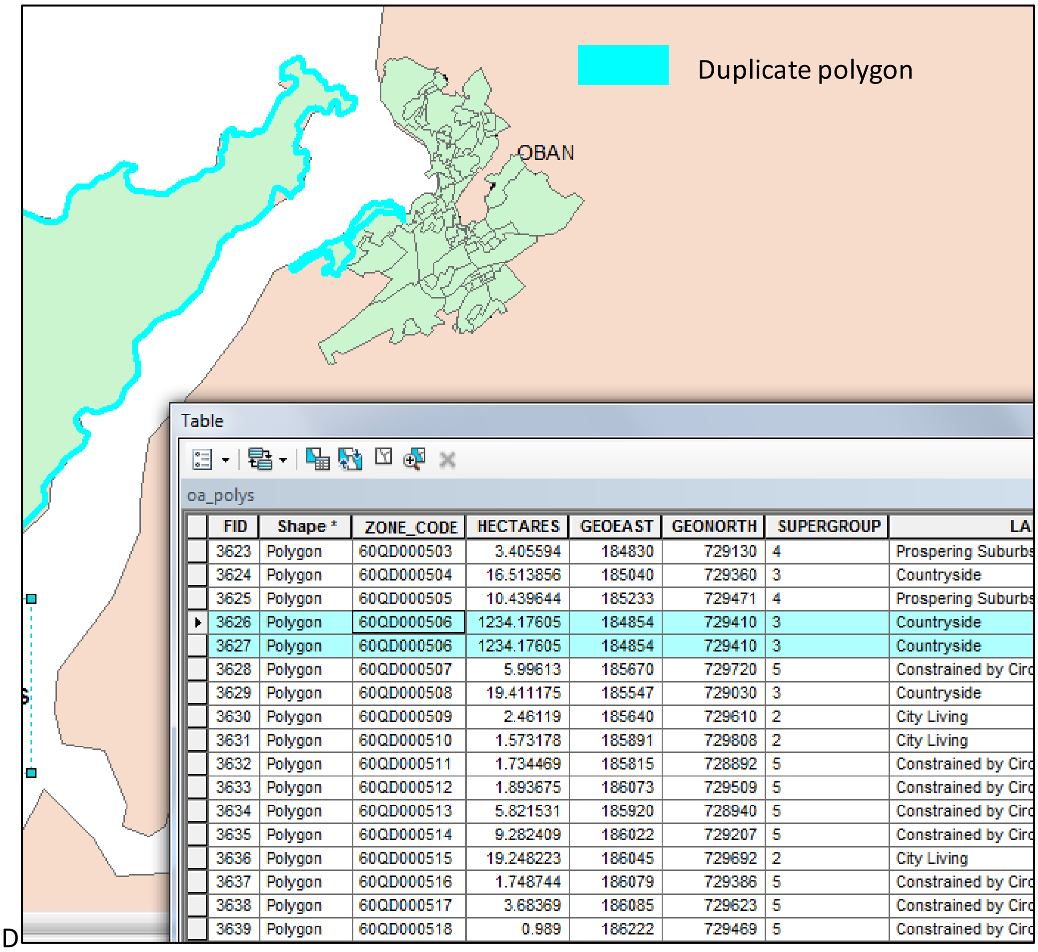
Figure 23 Output Areas (OAs) used in the study (n=30,066)



To create the neighbourhood geographies two types of buffers were created around the OA centroids. The Euclidean buffers were created by using the buffer tool in Arc GIS. To create the network buffers the two street network datasets, the ITN and UP layer described in Table 7, were joined using the merge function in Arc GIS. Network buffers were created using the Network Analyst function for 500m and 1000m zones around the centroids.

Inspection of the data revealed that surplus buffers had been created. These were identified as being in coastal areas, such as Oban, where there more than one buffer was created due to the proximity to island land areas (Figure 24). This was fixed by using the dissolve function in Arc GIS which removes boundaries between adjacent polygons having the same value for a specific attribute. The duplicate OAs had the same zone code so to remove the unwanted polygons the dissolve function by zone name was used which removed the extra unwanted buffer zones, keeping only the one closest to the centroid.

Figure 24 Example of a duplicate buffer zone created around the coastal town of Oban in Scotland



	FID	Shape *	ZONE_CODE	HECTARES	GEOEAST	GEONORTH	SUPERGROUP	LA
	3623	Polygon	60QD000503	3.405594	184830	729130	4	Prospering Suburbs
	3624	Polygon	60QD000504	16.513856	185040	729360	3	Countryside
	3625	Polygon	60QD000505	10.439644	185233	729471	4	Prospering Suburbs
▸	3626	Polygon	60QD000506	1234.17605	184854	729410	3	Countryside
	3627	Polygon	60QD000506	1234.17605	184854	729410	3	Countryside
	3628	Polygon	60QD000507	5.99613	185670	729720	5	Constrained by Circ
	3629	Polygon	60QD000508	19.411175	185547	729030	3	Countryside
	3630	Polygon	60QD000509	2.46119	185640	729610	2	City Living
	3631	Polygon	60QD000510	1.573178	185891	729808	2	City Living
	3632	Polygon	60QD000511	1.734469	185815	728892	5	Constrained by Circ
	3633	Polygon	60QD000512	1.893675	186073	729509	5	Constrained by Circ
	3634	Polygon	60QD000513	5.821531	185920	728940	5	Constrained by Circ
	3635	Polygon	60QD000514	9.282409	186022	729207	5	Constrained by Circ
	3636	Polygon	60QD000515	19.248223	186045	729692	2	City Living
	3637	Polygon	60QD000516	1.748744	186079	729386	5	Constrained by Circ
	3638	Polygon	60QD000517	3.68369	186085	729623	5	Constrained by Circ
	3639	Polygon	60QD000518	0.989	186222	729469	5	Constrained by Circ

4.3 Measures of the built environment

The four measures of the built environment chosen for this research were destination accessibility, street connectivity, residential density and walkability. These are considered to reflect Area Walking Potential (AWP). These features were selected because of the strength of the empirical and theoretical evidence supporting their associations with walking discussed in Chapter 3. In addition, a measure of area deprivation was developed to investigate the impact of area deprivation on walking and to examine inequalities in the distribution of the four AWP measures and relationships between AWP and walking.

4.3.1 Destination accessibility

In previous research, access to destinations showed some of the strongest associations with walking of the BE measures reviewed in Chapter 3. Destinations include the sorts of neighbourhood places people might want to walk to, such as shops, schools, parks and workplaces. More destinations are considered to encourage more walking. There are various ways of measuring access to destinations. Three commonly used approaches are Land Use Mix (LUM), counts of a single destination type within a specified area and a destinations accessibility index which measures access to various types of destinations within a specified area. A destinations accessibility index was selected as the most appropriate type of measure because there was more consistent evidence for associations with walking for this measure than land use mix, and land use data were not easily available. Using multiple destinations was considered to offer more insight into AWP than a measure of a single destination.

Different methods are used to calculate the presence and diversity of destinations which are summarised in Table 10. Method 1 involves counting each destination of interest and then giving a score based on the presence/absence of different types. This provides a measure of the diversity of destinations but does not indicate number of destinations. For example, an area with three schools and seven shops would receive the same score as an area with one school and one shop. Method 2 is a score based on the count of each type of destination but this does not account for destination diversity, for example an area with a shop, school, leisure centre and restaurant would receive the same score as an area with three schools and one shop.

Table 10 Comparison of methods for calculating destination accessibility

Method	Source	Advantages	Disadvantages
1. Sum of different category based on presence/absence of any destination within each category	Sugiyama et al. 2009	• Measure of destination diversity	• Does not consider prevalence of destinations • Does not include weightings that can be applied to different destinations to account for their relative importance for people's walking • Does not distinguish where access to more than one destination is likely to encourage walking or not
2. Score each category by prevalence of destinations and sum scores	Glazier et al. 2014	• Measure of prevalence of destinations	• Does not specifically consider diversity of destinations • Does not distinguish where access to more than one destination is likely to encourage walking or not
3. Sum of category scores based on presence/absence based on a list of all destinations considered to support walking	Witten et al. 2011	• Takes account of prevalence and diversity of destinations. • Differentiates where access to more than one destination is likely to encourage walking more than access to a single destination	• More complex measure to implement

Method 3 accounts for both prevalence and diversity of destinations and was selected for inclusion in the research. The method employed closely follows that of the National Destination Accessibility Index (NDAI) developed in New Zealand by Witten et al. (2011). This measure has the advantage of taking account of both presence and diversity of destinations and takes account of destinations that may influence both walking for transport and leisure. It is a validated measure which has been associated with walking behaviour in New Zealand (Witten et al. 2012). This destinations index was informed by users' perceptions of their environment, which was identified as a key omission in many objective studies of the BE and walking in chapter 2. As such it is considered an appropriate model for this research. The NDAI measure will be described briefly before introducing the version adapted for use in this Scottish study. The NDAI consists of 8 domains of destinations; education, transport, recreation, social and cultural, food retail, financial, health and other retail. These were derived using a photo-elicitation exercise in which participants of different ages and ethnic backgrounds from socially and geographically diverse New Zealand neighbourhoods were asked to take photographs of `what makes your neighbourhood good and not-so-good for walking?' (Witten et al. 2011). Within each of the domains there were subcategories of destinations (for example, in the financial domain there were two subcategories; banks/credit unions/ATMs and post offices. To calculate a destination accessibility score for neighbourhoods, each of the subcategories were assigned into a binary or tertiary score type. Where access to multiple types of a subcategory was not likely to encourage more walking (for example, a General Practitioners) it was given a binary score for presence or absence. If multiples of the destination were considered to encourage more walking (for example, retail outlets) then the category was given a score of between 0 and 3. A score of 0 indicated absence of the destination and scores between1-3 were allocated according to the relative number of amenities for all study sites. The domains were weighted by importance for walking. A total score for each neighbourhood was calculated based on the sum of the domain scores multiplied by the weighting.

A destinations measure for use in this research was developed closely following the NDAI but with adaptations for the urban Scottish context and Scottish data. The final dataset was selected for inclusion through consideration of their potential to support walking and empirical evidence of associations between destinations with walking. These measures were grouped into categories where the types of destinations were considered to have similar motivations for walking. The groupings also drew on the categorisation used in the NDAI. Eight domains of destination types were selected for inclusion in the study. Following the methodology of the NDAI several subcategories were created for each of the domains. A total of 144 destination types were selected for inclusion in the research. The 8 domains of destinations and subcategories is shown in Table 11. The full list of all types of destination within each subcategory is detailed in Appendix A. The data sources are shown in Table 12.

Table 11 Domains and subcategories of destinations used to create the destinations accessibility index

Domain	Subcategories
Health	Chemists
	Doctors surgeries
Public transit	public transport stations/stops
Education	secondary school
	primary schools
	Pre-school, afterschool
Open space	Accessible open space
Social and cultural	sports complexes, outdoor pursuits
	Alcohol outlets
	Eating and drinking
	Community centres
	Libraries
	Venues, stage and screen:
	Worship
	Attractions (museums, art galleries, historical, zoological and botanical)
Non-food retail	Clothing, accessories, household, office, leisure and garden
Financial	Cash machines cash points
	Post offices
Food retail	Supermarkets, frozen foods
	- Newsagents and tobacconists - Convenience and general - Alcoholic drinks
	Specialist, markets
	Convenience and general
Employment	Commercial
	Industrial
	Institutional

Table 12 Data and data sources used for creating the destinations accessibility index

Data	**Source**	**Description**
Ordnance Survey Points of Interest (PoI) data	Ordnance Survey by request (Ordnance Survey 2016b)	Points data of destinations and amenities
Green space	Greenspace Scotland by request (Greenspace Scotland 2011)	Polygon data for open space in open space in villages, towns and major urban areas in Scotland
Beaches	Edina Share Geo download (Mcilvenny 2012)	Intertidal land areas in Scotland

Ordnance Survey Points of Interest (PoI) data were obtained via request from Ordnance Survey. These data have been criticised, for example, Ellaway et al. (2014) found that in some cases, such as alcohol outlets in Glasgow, data did not match real time observations. This was attributed to their observations being carried out during a period when many off-licenses in Glasgow were closing and this transition may have resulted in OS having difficulties in gathering the data. However, this dataset was considered the most accurate and comprehensive available for this study. These data are and updated four times a year. Spot checks were carried out comparing the data with site visits which found the PoI dataset to be accurate. There was some duplication between health centres classified as 'clinics and health centres' and those classified as 'doctor's surgery'. In Edinburgh, there are a total of 51 clinics and health centres and 68 doctors' surgeries. 16 of these are classified as both. This appeared to be when the medical centre offered additional services to standard GP practices. For example, Hermitage Medical Practice and Morningside medical practices in Edinburgh are classified both as a 'Clinics and health centres' and 'Doctors surgery'. Hermitage Medical Practice has two separate surgeries on the same premises and Morningside has a sports injury and physiotherapy clinic on the same premises. Therefore, these were not considered to pose a significant issue for data accuracy as they were two different types of destination.

For the open spaces, the size of the area was considered of importance rather than just the number and diversity open space destinations. Open spaces that occupy a large area may make them more attractive or accessible as walking destinations (Giles-Corti, Broomhall, et al. 2005). Therefore, points data were not considered appropriate. Instead, greenspace data were sourced from Greenspace Scotland's 'Greenspace Map' (Greenspace Scotland 2011) This contains polygon data for open space in villages, towns and major urban areas in Scotland. Many of Scotland's settlements are situated near to the coast with access to beaches where walking can take place. Beach data are not included in the greenspace Scotland dataset, so these data were sourced via Edina's Share Geo database. This dataset contained intertidal areas around the coast of Scotland from MasterMap data which was classified using based on National Heritage Scotland's land classification (Mcilvenny 2012). The full list of greenspace destinations included is shown in Table 13. Open space was calculated as the proportion of the total area within each buffer zone. The open space data are coded by land use type. To obtain the open space data for included in this study, relevant land types were selected for using the select and extract tools in Arc GIS using these codes. The total land area for each type of land use was extracted using and intersect operation.

Table 13 Greenspace data used in the destination accessibility measure

Open space classification	**Description**
Public parks and gardens	Public parks and gardens
Amenity - business	General amenity (informal recreation, kickabouts, walking, sitting out) within industrial and business areas
Play space	Play space for children and teenagers
Green corridors	Accessible greenspace such as that associated with disused railway lines and paths, canal towpaths, accessible river corridors and the associated greenspace
Woodland	Areas of woodland with more than 20% closed canopy tree cover.
Open semi-natural	Areas of undeveloped or previous developed land with open natural habitats or which have been colonised by vegetation and wildlife.
Beaches	Accessible coastal areas

Following the method used by Witten et al. (2011), for some of the subcategories, the presence or absence of the destination was considered important for influencing walking. For these destinations, neighbourhoods were given a binary code of 1 for present or 0 for absence of the destination. For others, multiple destinations of the same type were considered more likely to encourage walking. For these, neighbourhoods were divided into tertiles according to the number of the destination in question and given a score of 1 for those in the lowest tertile to 3 for those in the highest tertile. If no such destination measures were present, the subcategory was given a score of 0. Table 14 summarises the decisions to categorise scores as binary or tertiary.

Table 14 Binary/tertiary measurement used for categories in the destinations accessibility measure

Binary/ tertiary	Destination type	Rationale for type of category
Binary	Health destinations	People are registered at only one GP surgery. Chemists tend to be similar and it is unlikely that multiple chemists will significantly alter walking tendencies.
	Educational institutions	People usually attend one educational institution. The exception may be parents who walk to drop off/collect their children at different institutions.
	Social and cultural destinations	Individual social and cultural destinations such as churches or cinemas are likely to be individually attractive (for example, people are not more likely to walk if there are two churches than if there is one).
	Financial institutions	People tend to visit one financial institution such as a bank or building society.
	Food retail	Individual types of food retail outlets such as supermarkets are considered single destinations.
Tertiary	Public transit	One public transit station is likely to have a limited number of destinations. The more transit stops there are (for example a bus stop and a rail station) the more journey options people have.
	Open space	Greater open space area may be more attractive than smaller destinations as there are more access points and a wider area within which to walk.
	Employment	One employment destination will only be a walking destination for a limited number of residents who work at the specified destination. More destinations mean that more residents are more likely to work at these places.
	Non-food retail	Multiple types of retail outlet (for example, multiple clothes shops) may be more attractive as a walking destination than a single type retail outlet because this gives more choice and more potential for accomplishing shopping tasks

The categories were weighted because different types of destinations are unlikely to exert an equal effect on individuals' motivations for walking. For instance, for many people the local recreational amenities are likely to be a more regular neighbourhood destination than health service facilities and, hence, access to a range of local recreational amenities may enhance population-level physical activity more than good neighbourhood access to a General Practitioner. Therefore, a weighting, informed by theoretical rationale, the NDAI and other evidence from the literature (for example, Diez Roux et al. 2007; McCormack et al. 2008), ranging from 2 to 5 was applied to each category. Table 15 details the destination domains, subcategories, whether the subcategories were binary or tertiles and weightings.

Table 15 Destinations data (showing categories, subcategories data source, type weighting and rationale for inclusion) used to construct the destination accessibility index

Primary Category	Subcategories	Data type	Possible subcategory score	weight	Weighting rationale
Health	Chemists/pharmacies	Binary	0/1	2	Occassional access but essential service
	Doctors surgeries	Binary	0/1		
Public transit	public transport stations/stops	Tertile	0 -3	5	Accessed frequently, potentially used by many
Education	Secondary school	Binary	0/1	4	Accessed frequently but only by certain groups
	Primary schools	Binary	0/1		
	Pre school, afterschool	Binary	0/1		
Outdoor recreation	Accessible open space	Tertile	0 -3	5	Walking destination comprising scope for walking within
Social and cultural	Sports	Binary	0/1	3	Accessed by some but not essential day to day activity
	Pubs and bars	Binary	0/1		
	Eating and drinking	Binary	0/1		
	Community centres	Binary	0/1		
	Libraries	Binary	0/1		
	Venues, stage and screen	Binary	0/1		
	Worship	Binary	0/1		
	Attractions (museums, art galleries, historical, zoological and botanical)	Binary	0/1		
Non-food retail	Clothing and accessories; houshold, office, leisure and garden	Tertile	0-3	4	Frequent access open to all but not as frequent as food retail
Financial	Cash machines cash points	Binary	0/1	3	Less frequent access
	Post offices	Binary	0/1		
Food retail	Supermarkets, frozen foods	Tertile	0/1	5	Access frequently and likely to be used by many
	Newsagents and tobaccanists, alcoholic drinks (off-licences, wholesalers))	Binary	0/1		
	specialist shops, markets	Binary	0/1		
	convenience and general	Binary	0/1		
Employment destinations	Commercial	Tertile	0-3	2	Frequent access but only affecting those who work near to home
	Industrial	Tertile	0-3		
	Institutional	Tertile	0-3		

The process used to calculate the total destination accessibility index score for each neighbourhood is detailed below:

1. Counts of each of the 144 destinations were taken for each buffer zone in both 500m and 100m zones using a spatial join 'count' operation in Arc GIS. (This was automated using the model builder tool in Arc GIS).
2. PoI counts were downloaded into Excel and counts of the destinations for each subcategory were summed.
    i. For binary measures, a score of 1 was allocated if any of the destinations were present and 0 if there were none.

    ii. For destinations measured using tertiles, neighbourhoods were ranked according and given a score of between 1 and 3 where 1 had the lowest and 3 had the highest number of destinations.

3. The total land use for each type of greenspace and beach area within each study site was summed and then the study sites were ranked into tertiles according to the total amount of greenspace in each.
4. Scores for subcategories were summed to calculate the category score, these were then standardised by being divided by the maximum possible score for the category resulting in a score between of 0-1.
5. The standardised domain scores were multiplied by their weighting and then summed to give a total destination accessibility score of 0-33 for each neighbourhood.

4.3.2 Street connectivity

Street connectivity was calculated by counting the number of street intersections with at least three or more turn options (known as 'real' or 'true' intersections) within a specified area (Forsyth 2010). Street connectivity measured in this manner has been positively associated with walking outcomes in previous studies (Sundquist et al. 2011; Turrell et al. 2013) and is recommended by IPEN (IPEN, 2013). Several roads datasets were considered for calculating intersection density. These are shown in Table 16 and include the Ordnance Survey Integrated Transport Network (ITN) layer, an adjusted ITN layer, the OS MasterMap Topography layer and the OS MasterMap Meridian layer.

Table 16 Scottish roads datasets considered for calculating intersection density

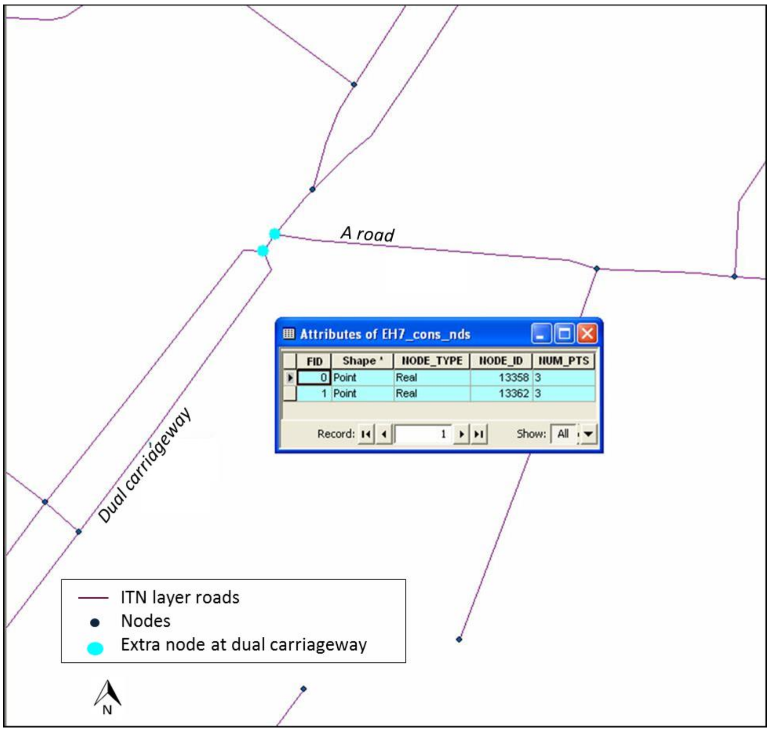
Dataset	Source	Details	Advantages	Disadvantages
1. Ordnance Survey MasterMap ITN layer.	Edina Digimap	Includes public and private roads. A road is defined as a metalled way driveable by an ordinary vehicle such as a family car. Tracks are not included within the ITN Layer.	• High level of detail and excellent coverage. • Compatible with Urban Paths data. • Takes account of elevation and so includes turn restrictions for bridges • More comprehensive coverage than the Meridian layer	• Does not include footpaths. • Includes two parallel roads for dual carriageways with intersections on each, therefore, leading to over-count of intersections on dual carriageways.
2. MasterMap ITN layer.	Edina ShareGeo database	A processed version of the ITN layer with pedestrianised roads and road routing restrictions added.	• Incorporates both roads and footpaths	• Contains road routing turn restrictions
3. MasterMap Topography layer	Edina Digimap	Features that represent objects in the physical environment such as roads, footpaths, buildings, fields, fences and post boxes, as well as intangible objects such as county boundaries.	• Has both footpaths and roads • Does not include traffic routing restrictions	• Data format not compatible with requirements for calculating nodes
4. Ordnance survey MasterMap Meridian Layer	Ordnance Survey (Ordnance Survey 2016a)	Variety of Ordnance Survey data sets including roads network	• Portrays most* dual carriage ways as single roads and therefore does not over count intersections	• Not compatible with Urban Paths dataset therefore not possible to include footpaths • Not as complete coverage as the ITN layer • Does not take account of elevation and so does not include turn restrictions for bridges
5. Ordnance Survey Urban Paths dataset	Edina Digimap	Urban path network includes paths suitable for non-vehicular users including pedestrians, cyclists and wheelchair users. Covers urban areas with an individual extent greater than 5 Km^2.	• Covers non-vehicular paths which are important for facilitating walking.	• Does not include vehicular roads • Only available for settlements of at least $5km^2$

** Not quite all dual carriageways, for example, Leith Walk, an A road in Edinburgh. This issue was queried with Edina and is because Leith Walk used to be two parallel roads, but the walk was widened and is now one, but each side of the road has different street names. However, due to the unusual circumstance of this error it is unlikely that this type of problem would be common.*

Roads data

The most appropriate roads dataset identified was the ITN layer. This aims to have the most comprehensive and up-to-date coverage of Britain's roads available (OS 2013). This dataset does not include non-vehicular roads such as passageways, which are important for supporting walking. The OS Urban Paths dataset captures non-vehicular roads which are designed to be compatible with the ITN layer. The main disadvantage of the ITN layer is that it includes two parallel roads for dual carriageways. This results in an over-count of intersections along dual carriageways, because it doubles the number of intersections at dual carriageways. This is depicted in Figure 25 which highlights two intersections (nodes) where there should only be one. Attempts were made to overcome the problem of double roads for dual carriageways, for example, using the Point & Polyline Tool Polyline Consolidator option in the Point & Polyline tool in Arc GIS, but none removed the extra nodes.

Figure 25 Section of the road network in urban Scotland showing an example of an intersection over count using the ITN (Integrated Transport Network) roads dataset



Other datasets were considered but close investigation of these datasets revealed significant disadvantages making them less suitable for use in the study. An alternative ITN layer dataset (dataset 2 in Table 16) was available from Edina's Geo Share database. This dataset included footpaths which would have removed the need to join the ITN layer to the UP data. However, this dataset included road routing turn restrictions for vehicles such as restrictions on one way streets or no right turn restrictions. This meant that a four-way intersection where the traffic is right turn only would only be counted as having two turning options, whereas from a pedestrian perspective it has three. Therefore, this dataset was rejected because it did not reflect the pedestrian walking experience.

The MasterMap Topography layer (dataset 3 in Table 16) includes footpaths. However, it was not possible to count intersections in GIS using Point & Polyline tool (see subsequent description of the calculation of the measure) and therefore proceeding with this dataset was not possible. The Ordnance Survey MasterMap Meridian dataset (dataset 4 in Table 16) includes only single roads for dual carriageways, overcoming the problem of the intersection over count for dual carriageways. However, the Meridian data offers much less extensive coverage of Scottish roads than the ITN layer. This is evident in Figure 26 which shows the ITN layer in brown and the Meridian layer in blue, the brown ITN layer is evident where the Meridian layer is not. Secondly, the urban paths dataset was not compatible with the Meridian data because the two datasets did not successfully join using the Join function in GIS. This resulted in 'floating' sections of roads where the two datasets did not meet. Examples of such problems are highlighted in Figure 27 which shows the Meridian and UPs datasets. This issue results in an undercount of real intersections since these datasets do not show where roads connect with footpaths. By contrast, the UP data is designed to be used in conjunction with the ITN layer meaning that these two datasets can be successfully joined. The limitations posed by the ITN layer regarding the over count of some intersections was deemed less significant than the problems with using the alternative datasets, particularly due to the accuracy and extensive coverage of these data compared with the other.

Figure 26 Section of an urban Scottish Roads network showing ITN (Integrated Transport Network), Meridian and UP (Urban Paths) networks

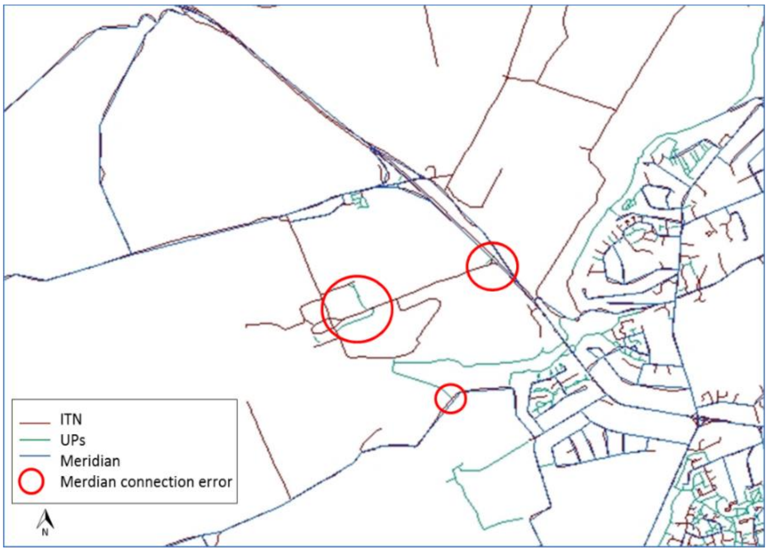
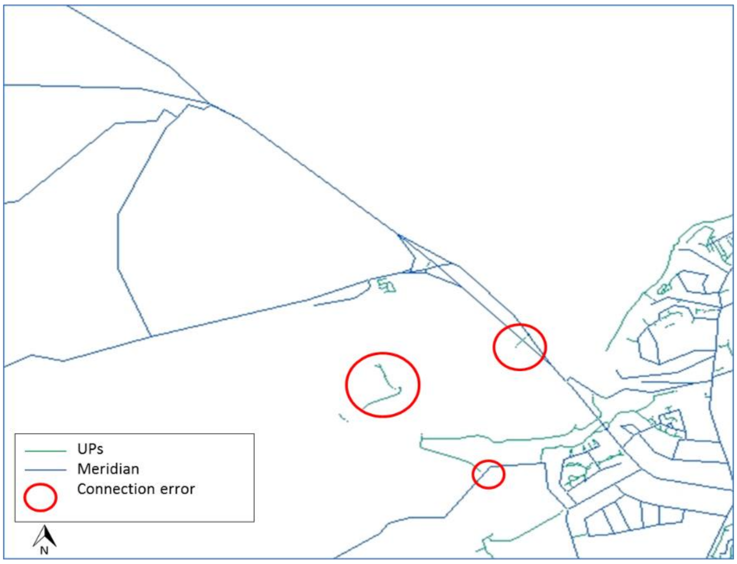


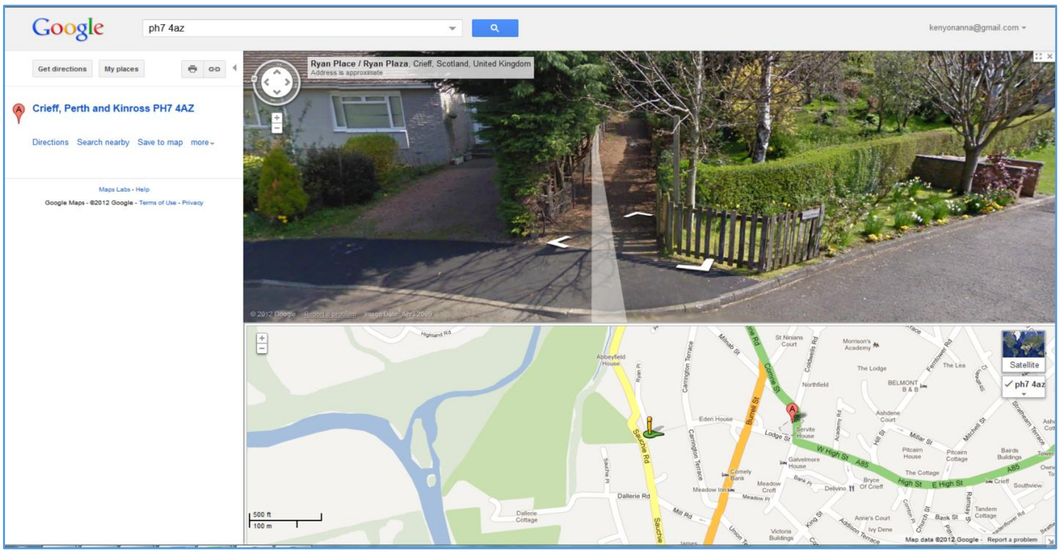
Figure 27 Section of urban roads in Scotland showing the UPs (urban paths) and Meridian roads layers and problems with connections between the datasets



Non-vehicular paths data

The review of evidence in chapter 3 showed the importance of non-vehicular routes for pedestrian travel. The Ordnance Survey Urban Paths (UP) dataset contains non-vehicular paths in settlements of at least 5km². Initially, small towns (urban/rural classification folds 3 and 4 were included in this research. However, the UR classification system contains no information on settlement land area. Therefore, to ensure that these data were for inclusion in this study, spot checks were carried out to determine whether the UP data were present in all the OAs selected for inclusion. OAs that fell into categories 3 and 4 were cross referenced with the same places in Google Maps and non-vehicular paths were identified in Google Maps that were not present in the UP dataset (for example Figure 28). Similar checks were carried out for the presence of urban paths in larger settlements (U/R classification folds 1 and 2) and no missing connecting UPs from UR folds 1 and 2 were found.

Figure 28 A non-vehicular path in an UR classification fold 4 area not included in the UP dataset

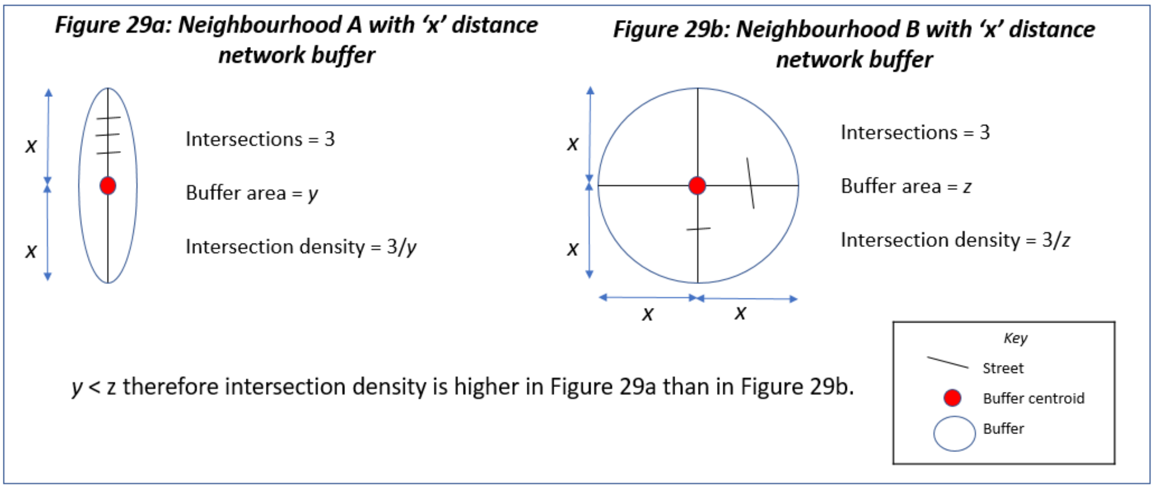


An alternative dataset containing non vehicular roads was investigated. The roads, tracks and paths (RTP) data from Mastermap Topography layer (dataset 3 in Table 16) contains non-vehicular roads. Comparison of the RTP and the UP data showed that RTP data were present in an UR fold 4 area where UP were not. However, generally, the coverage of non-vehicular paths in the UP dataset was much more extensive than the RTP data. Therefore OAs falling into areas classified as UR 3 and 4 areas were removed because using areas classified as 3 and 4 resulted in incomplete coverage of non-vehicular paths in the study zones. A disadvangate to this option was the resulting ommission of specific geographic sections of Scotland, notably in the majority of the northern and western regions and the Islands which did not have any OAs classified as falling into UR 1 and 2 areas because of the smaller size of settlements in these areas. However, this research is concerned with invesigating AWP in urban Scotland specifically and so using the areas classified as the two most urbanised was considered to be appropriate.

A general limitation of the roads datasets discussed is the inclusion of all A roads, since some of these roads are not walkable. An example of such a road is the Edinburgh City Bypass (A720) which is inaccessible to pedestrians. This could result in intersection density counts over counting the turn options available to pedestrians in areas where roads are not accessible to pedestrians. This may be an issue due to proximate populations however, there are few turning options within 500 and 1000m of such roads and therefore would result in a very limited over count of intersections. Finally, some roads are only accessible at certain times of day or may incur a fee for use such as in Edinburgh's botanical gardens. It was not possible to identify paths that are only accessible for part of the time or that incur a fee for use from the UP or ITN data. However, such routes are uncommon and were not considered to substantially limit the viability of the measure.

Intersection density was calculated using a Euclidean buffer around OA centroids instead of the street network buffer to create neighbourhoods. This is because network buffers vary according to the configuration of streets. For example, more linear configurations of intersections results in smaller network buffers, which would result in higher intersection density compared with places with a less linear distribution of intersections. For example, Figure 29a shows hypothetical 'Neighbourhood A' in which there are three real intersections contained within a network buffer. In hypothetical 'Neighbourhood B' there are also three intersections but these are less linear so the network buffer is much larger. Despite the 'Neighbourhoods' having equal numbers of intersections, the intersection density score would be higher in 'Neighbourhood A', yet this configuration of streets is not necessarily better for walking. A Euclidean buffer provides a consistent neighbourhood land area which facilitates comparison of the number of intersections between neighbourhoods. Using a Euclidean buffer would result in the same intersection density score for 'Neighbourhoods' A and B as there are the same number of intersections. A potential disadvantage of this measure is that it does not take account of the configuration of the street network, which may affect how easy it is to walk around. However, for the purposes of this research the number of intersections within each neighbourhood was considered adequate and has been used in many other studies as discussed at the beginning of this section. Intersection density as a measure of connectivity is critiqued in more detail in section 7.3.3.

Figure 29 showing high and low connectivity measured using network and Euclidean buffers



To calculate intersection density for each neighbourhood, the following process was carried out:

1. Combined ITN and UP datasets were merged.
2. The number of number of intersections were identified using the Point & Polyline tool in Arc GIS (this extracts all intersections, giving a count of the number of turn options available).
3. Intersections with fewer than three turn options were deleted using the 'select by attribute' tool in Arc GIS and selecting only real intersections with three or more turn options.
4. The number of intersections within each study site buffer zone were calculated using a Spatial Join and summing the number of intersections.

4.3.3 Residential density

Residential density can be calculated in different ways which are summarised in Table 17. Method 1 calculates the number of residences per land use area. This is a commonly used measure of residential density (for example, Kerr et al., 2013, Sundquist et al., 2011). However, residential land use data were not available for Scotland. The second method in Table 17 indicates both the compactness and prevalence of residences because it considers the number of properties per residential building area and per total land area and was considered the most explanatory option to representing residential density. Attempts were made to use Ordnance Survey Address layer 2 data to identify the number of residences and the Ordnance Survey Mastermap Topography layer to extract residential building area. However, it was not possible to join these datasets in GIS and so this measure was infeasible. Instead residential density was calculated by dividing the number of residences within the zone by the total land area (method 3 in Table 17). This method is suitable because it results in a comparable measure of density across study sites that indicates the prevalence of dwellings within each. A limitation of this measure is that it does indicate how compact or spread out residences are within the buffer zone. However, it gives an accurate indication of the number of residences encountered by people walking within the specified neighbourhood areas.

Table 17 Comparison of measurement options for calculating residential density

Measure	**Calculation**	**Advantages**	**Disadvantages**
1. Number of residential units per residential land area	n residential units /residential land area (Ha)	Indicates compactness of residences.	Land use data unavailable
2. Number of residential units multiplied by the total residential building area per land area	n residential units X residential building area / land area (Ha)	Can give an indication of a combination of compactness and prevalence	Building area data not compatible with address count data. Dataset only measured building land use in 2 dimensions therefore did not take account of blocks of flats.
3. Number of residential units per land area	n residential units/land area (Ha)	Indicates number of residences within a specified walking zone. Available data for Scotland	Does not account for how compact the residences are within specified area

Residential density was calculated using the following process:

1. Data on residence counts were downloaded from Edina derived from census data. These data comprised postcode centroids with residence counts for the geographic postcode units in the year 2010.
2. The number of address counts within each neighbourhood was calculated by using the spatial join function in Arc GIS and selecting 'sum' as the outcome.
3. The land area of each neighbourhood was determined using the Arc GIS function by creating a new field in the attribute table and selecting 'Geometry'.
4. Residential density was then calculated by dividing the number of residences per Hectare (Ha).

A small number of study sites showed a residential density count of 0. This was unexpected because the most urbanised output areas in Scotland had been selected. The output area was investigated by matching the OA code to the area's three composite postcodes using look up tables from General Register Office for Scotland (National Records of Scotland 2001) The postcodes were checked using Google Maps 'street view' and satellite imaging. The result suggested that although there were residences present there were two residential clusters on either side of a strip of industrial land and greenspace, suggesting that it is plausible that the geographic centroid of this output area did not contain any residences within 1000m. A further potential limitation of this measure is that it counts the number of residences based on postcode centroids that fall within the buffer zones. These are either 'in' or 'out' of the buffer zone which may result in small over counts or undercounts of actual residences where only part of the postcode area was inside the buffer. However, this error is minimised by the small number of residences in postcode units which contain approximately 15 residential addresses.

4.3.4 Walkability

The walkability measure was constructed from the three built environment measures selected for inclusion in this study (destination accessibility, street connectivity and residential density) and so reflected multiple facets of the BE. Consideration was given to the relative importance of each of the composite measures on walking. Weightings of component measures can be used to adjust the walkability score. An iterative process can be used in the creation of walkability measures, where different weights are applied to the measure and outcomes are compared, to decide on the measure that is most closely associated with the outcome of interest. For example Frank *et al.*, (2010) calculated walkability weighting residential density, RFAR and LUM equally but applying a weight of 2 to intersection density. The authors justified this based on prior evidence regarding reported utilitarian walking distances and the resulting strong impact of street connectivity. Then different iterations between alternative weighting schemes led to the emergence of distinctive neighbourhood types and weighting schemes were evaluated based on expert opinion and against primary data collection on pedestrian travel. It was not possible to use this type of approach in this study because the outcome data was not available prior to the creation of the BE measures (see section 4.5 describing the process of obtaining the outcome variables). Therefore, in devising the measure for this study consideration was given to weightings used in previous measures of walkability and theoretical and empirical evidence of the relative influence of each BE measure. Table 18 shows weightings that have been applied in other walkability research.

Table 18 Walkability weightings used in other GIS-derived walkability measures

Source	Walkability measure	Rationale
Frank et al. 2010, Frank et al. 2006	2xZ intersection density + Z residential density + Z retail floor area ratio + Z land use mix	No rationale was given for the calculation in the 2006 study. However, in the 2010 study the weighting applied to street connectivity was justified based on prior evidence regarding reported utilitarian walking distances and the resulting strong impact of street connectivity. Further input confirming this weighting scheme was obtained through iterations between alternative weighting schemes and resulting neighbourhood types that emerged. Census block groups and corresponding neighbourhoods selected with different weighting schemes were evaluated based on expert opinion and against primary data collection on pedestrian travel.
Leslie et al. 2007	Sum of scores ranked into deciles for: dwelling density + intersection density + land use mix + net retail area	No explanation was given for the equal weighting applied to these measures, but the paper described their measure as building upon that of Frank et al. (2006) and adapted to the Australian context.
Owen et al. 2007	Z dwelling density + 2 X Z street connectivity + Z land-use mix + Z net retail area	References Frank et al. (2006) which did not describe the rationale for the weighting
Van Dyck et al. 2010	Z residential density + 2 X Z intersection density + Z land use mix	Not explicitly given but reference Frank et al. (2010) and Leslie et al. (2007)
Sundquist et al. 2011	Z residential density + 1.5 x Z street connectivity + Z land use mix	Based on previous work by Frank et al. (2006) which weights connectivity x 2, although the rationale for this weighting was not given in the study by Frank et al. Sundquist et al. (2011) weighted connectivity by 1.5 because their walkability index was based on three items instead of four used by Frank et al. (2006).
Freeman et al. 2013	Z residential density + Z intersection density + Z land use mix + Z subway stop density + Z ratio of retail building floor area to retail land area.	No explanation was given for the equal weighting applied to these measures

Three BE measures were used to calculate walkability, intersection density, residential density and walkability. Intersection density was given a weighting of two which corresponds with the higher weighting given to street connectivity in other measures of walkability (Frank et al. 2006, Owen et al. 2007, Van Dyck et al. 2010, Sundquist et al.

2011) and reflects the strong associations found between street connectivity and walking in the empirical literature review.

A weighting of two was applied to destination accessibility and intersection density (street connectivity), and no weight was applied to residential density. A higher weighting was applied to destination accessibility because of the strong evidence found for associations between destination accessibility and walking in the review of the literature. Destination accessibility is rarely applied in composite measures of walkability; instead a measure of land use mix is more frequently used and is frequently weighted lower than for intersection density (Frank et al. 2006, Owen et al. 2007, Van Dyck et al. 2010, Sundquist et al. 2011). However, in the review of the empirical literature stronger associations with walking were found for destination accessibility than for land use mix and therefore it was considered appropriate to weight this more than the LUM measure. Additionally, the destinations accessibility measure is based on the NDAI (Witten, Pearce, et al. 2011) which was designed specifically to measure destinations that are associated with walking.

Residential density was given a lower ranking than the other two measures which is consistent with the approach taken in other studies (Frank et al. 2006, Owen et al. 2007, Van Dyck et al. 2010, Sundquist et al. 2011) and reflects the stronger evidence for the influence of street connectivity than for residential density in the review of the empirical literature. Furthermore, much of the evidence of positive associations between residential density and physical activity comes from a US setting where residential density is often lower than in the UK (Townshend & Lake 2009). Finally, it was hypothesised that areas with very highest residential density scores (large high rise flats) are not necessarily conducive to walking and as such this measure was considered less important for walkability than street connectivity and destinations accessibility. Based on this reasoning, the residential density score was given a weight of 1, or not weighted.

To calculate walkability, scores for each measure needed to be standardised so that they could be combined. Z scores were used to standardise score and the walkability calculation was carried out using the following methodology:

1. Z scores were created for each built environment measure by subtracting the mean from each data value and then dividing the result by the standard deviation using the formula:

$Z = (Y_1 - \hat{Y})/\text{St. Dev}$

(Frank et al. 2010, Marsh and Elliot 2008)

2. Walkability was calculated as per below:

Walkability = 2 x Z destination accessibility + Z residential density + 2 x Z intersection density.

3. Scores were standardized into z scores in SPSS by using the 'save standardised values as variables' option in Descriptive statistics.
4. These data were exported into Excel where weighting for the destinations score was applied by multiplying the standardised score by 2.
5. Scores were appended to the study sites using a 'Table join' function.

4.3.5 Area level deprivation

A measure of area deprivation was used to evaluate associations between area deprivation with AWP. This was used to examine associations between area deprivation and walking. The analysis also tested whether relationships between AWP and walking varied in areas with different levels of area deprivation. Types of area deprivation used in other relevant research include area level income (Nagel et al., 2008; Owen et al. 2007), crime (Nagel et al., 2008), safety (Nagel et al., 2008) and neighbourhood SES (Sundquist et al., 2011; Witten et al., 2012). The Scottish Index of Multiple Deprivation (SIMD) provides a measure of area deprivation taken at datazone level in Scotland. While data at the OA level would be more closely reflect the neighbourhood geography, the SIMD is not available at OA level. Datazones contain between 500 and 1,000 household residents compared with OAs which contain 20 to 50 households. The SIMD is a detailed and validated measure of area deprivation designed for use in Scotland and so was considered appropriate for this research. The SIMD ranks Scotland's 6,505 datazones in order of deprivation with 1 being the most deprived to 6505 being the least deprived. The seven domains used to calculate the SIMD are:

- Current Income
- Employment
- Health
- Education, Skills and Training
- Geographic Access to Services
- Housing
- Crime

(SIMD, 2009b).

The access to geographic services domain is based on drive times to shops and services such as GPs and public transport. For the purposes of this study, it was necessary to omit this domain from the measure because access to destinations is already included in the study as an independent built environment measure.

The SIMD ranked score for each datazone is calculated using a variety of 'indicators' for each domain. Domain scores are then ranked, standardised and transformed to create an exponential distribution. These scores are then weighted based on the importance of each element of deprivation and how robust the data are[2]. The weighted scores for each 1datazone are then ranked which creates the final SIMD rank. The higher the score,

[2] This information regarding weighting was obtained through email correspondence with the Scottish Government's Office of the Chief Statistician in June 2012.

the lower the rank and, the greater the deprivation (SIMD 2009). The SIMD methodology, indicators and weightings for each domain are shown in Appendix B. To create the alternative version of area deprivation was created without the access to services domain, transformed domain ranks for datazones without the area deprivation measure were supplied by the Scottish Government's Office of the Chief Statistician & Performance upon request. These scores were then weighted using the same weightings as for the SIMD. These weighted domain scores and then summed and then ranked to give a datazone level score based on this adjusted version of the SIMD.

Each OA in the study was given the score for the datazone into which it fell using lookup tables from the Scottish' Government's Scottish Neighbourhood Statistics (The Scottish Government 2009). These were ranked so that lower ranks indicated less deprivation and higher ranks indicated higher (worse) deprivation. The ranked scores were divided into quartiles for the purposes of the analysis (described in Section 4.8.1) and the quartile scores were appended to individual level data from the Scottish Health Survey (see Section 4.8). The new area deprivation measure was compared with the standard SIMD quintiles available from the Scottish Health Survey to ensure that the data had been calculated correctly. Table 19 shows that the quartiles assigned the area deprivation measure and the SIMD were similar, OAs at the in the most and least deprived quartiles falling into the same category in either indices, or a shift of only one quartile/quintile.

Table 19 Cross tabulation of numbers of respondents within area deprivation measure quartiles and in 2009 SIMD quintiles (n=4,456)

	Study quartiles				
SIMD Quintiles	Quartile 1 (least deprived)	Quartile 2	Quartile 3	Quartile 4 (most deprived)	Total
1st - most deprived	0	0	90	1,227	1,317
2nd	0	44	933	0	977
3rd	0	644	14	0	658
4th	162	407	0	0	569
5th - least deprived	935	0	0	0	935
Total	1,097	1,095	1,037	1,227	4,456

A comparison of deprivation scores for the study sample OAs compared with the whole of Scotland is detailed in Table 20. The equal maximum and minimum scores show that the range of deprivation is the same for the study sample as the rest of the country. However, the study sample has a higher proportion of OAs with high deprivation, as shown by the higher mean and median deprivation scores in the study sample (a mean of 1019.1 in study sample OAs compared with 891.8 for Scotland and median scores of 849.6 and 683.9 respectively). This difference is likely to arise because the OAs used in this study were the more urbanised areas of Scotland, including cities such as Glasgow and Fife which have some of the highest deprivation in Scotland (Scottish Government, 2011, Transport Scotland, 2005).

Table 20 Area deprivation summary statistics for OAs used in the study and for the whole of Scotland

Area level deprivation score	Study	Scotland
Minimum	2.1	2.1
Maximum	3809.5	3809.5
Mean	1019.5	891.8
Median	849.6	683.9

Area level deprivation scores are based on weighted summed measure of: Income, Employment, Health, Education, skills and training and Crime and Housing. Scores for each domain are calculated using a variety of indicators and then standardised before being weighted and summed.

4.4 Spatial analysis of the built environments measures across Scotland

The aim of this part of the study was to examine the geographic distribution AWP in urban Scotland. The aims of this analysis were to investigate:

1. The distribution of the built environment measures across Scotland
2. Relationships between AWP and area deprivation

4.4.1 The distribution of the AWP across Scotland

The distribution of built environment measures was analysed to assess whether there were geographic inconsistencies and inequalities in access. The scores for the four AWP measures were analysed using summary statistics and skewness scores to show the distribution of the scores across output areas. Scores for 500m and 1000m zones were compared to consider whether the distribution was affected by the zone size. Choropleth maps were used to examine the distribution of the AWP measures.

Relationships between population density and built environment were evaluated to show whether there are inequalities in access to walking environments for people living in areas with different levels of population density. If strong associations exist, then population density could be considered as a covariate in the analysis. Population density data for OAs was sourced from CASWEB which holds 2001 census data (UK Data Service Census Support 2013).

4.4.2 Relationship between built environment measures considered to support walking with area level deprivation

Relationships between area deprivation and built environment measures were considered to establish whether residents in more disadvantaged areas have equitable access to built environments considered conducive to walking. Three stages of analysis were employed for this:

1. Spearman's correlation coefficient (rs) was used to compare the strength of relationships between built environment measure scores and deprivation scores within output areas.

2. Mean built environment measure scores were compared between deprivation quartiles. This gives an indication of the consistency of any associations and whether there is a dose response relationship between deprivation density and built environment measure scores.

3. AWP measures were divided into quartiles, and their distribution within deprivation quartiles was analysed to investigate whether trends were consistent when using quartile measures. Gamma tests of association were used to calculate the strength of the associations. Gamma tests can be used to compare relationships between ordinal data. Gamma computes the ratio of the number of concordant pairs of variables minus the number of discordant pairs to the total of all pairs. The Gamma result takes a value of between -1 and 1 where a value of 0 indicates an absence of a relationship and values closer to -1 or 1 indicate stronger relationships. A Gamma result of 1.00 reflects a positive perfect relationship between variables; a Gamma of -1.00 reflects a negative perfect relationship (Fielding & Gilbert 2000).

4.5 Analytical strategy for relationships between built environment measures and walking.

The following section describes the analytical strategy for examining the relationship between AWP and walking and the preparation of the data for this analysis. Individual level data on walking behaviour and demographics were obtained from the Scottish Health Survey (SHeS). This is a nationally representative annual survey. It provides regular information on aspects of the public's health and factors related to health which cannot be obtained from other sources. Data from the 2010 version of the survey were used as these were the most recent data available at the time the analysis was carried out. 7,245 adults took part in this survey (Bromley et al. 2011). To comply with survey respondent confidentiality, all potentially identifying information needed to be removed prior to sending the AWP data. Therefore, it was not possible to use raw score data for the built environment measures because this would have meant that there were unique combinations of built environment measure scores, making it possible to identify respondents Output Area of residence after the data had been received. Therefore, the built environment and area level deprivation measures were divided into groups so that no unique combinations of scores remained. A trial and error process was used to identify the maximum number of groups possible (and more precise built environment and area deprivation indicators) without creating any unique combinations of scores. This was found to be quartiles, and so all built environment measures and the area deprivation measure were divided into quartiles for the analysis. This was carried out by ranking study sites by scores for AWP and area deprivation. Each neighbourhood was given a quartile score of 1-4 for each measure. A score of one indicated lowest prevalence of the measure (and hypothesised worst walking conditions) and four indicated highest prevalence of the measure (and hypothesised best walking environment). Quartile scores and their accompanying OA reference were sent to the SHeS team at the Scottish Government. Where available, individual level data were appended to the neighbourhood level data for individuals living in the OAs around which the neighbourhoods were created.

The use of these data required ethical approval which was obtained from the Multi-Centre Research Ethics Committee of Wales (REC reference numbers: 07/MRE09/55 and 08/MRE09/62). The following section describes the selection of the individual level variables requested from the SHeS.

4.5.1 Walking outcomes

Four walking outcomes were considered: likelihood of any walking in the previous four weeks, likelihood of doing more than one walk on any day in the previous four weeks, likelihood of achieving 30 minutes walking on any day in the previous four weeks and average weekly walking minutes, these are shown in Table 21. These variables address any walking, frequency of walks, health-related walking and total time spent walking. Thus, this analysis has the advantage of allowing comparisons of multiple types of walking outcome with each built environment measure. The full list of walking related variables that were available from the SHeS are shown in Appendix C.

Table 21 Walking outcome variables selected from the 2010 Scottish Health Survey for inclusion in the analysis

Walking outcome	**Research question**	**SHeS Questionnaire variable**	**Data type**
1	Whether did any walking	In the past four weeks, that is since [date four weeks ago] have you done a continuous walk that lasted at least 10 minutes?	Binary (Yes/no)
2	Frequency of walking (multiple walks)	On any day in the previous four weeks did you do more than one continuous walk lasting at least 10 minutes?	Binary (Any/none)
3	Achieving 30 minutes walking	Number of days walking 30+ mins brisk/fast including 10-30 min bouts in past 4 weeks	Converted to a binary variable (any /none)
4	Total time spent walking	Average time spent walking per week brisk/fast (derived)	Continuous

Any or multiple walks of ten minutes

Walking outcomes 1 and 2 relate to whether people did any walks or more than one walk of at least ten minutes in the previous four weeks, thus measuring any walking and frequency of walking. Both likelihood of any walking and frequency of walks are measures used in other literature (Duncan et al., 2010, Learnihan et al., 2011, Nathan et al., 2012, Sundquist et al., 2011). Data were also available on five minute walks (see Appendix C), but ten minute walks were considered more appropriate for testing associations with built environment measures and ten minutes is used in other relevant literature (Duncan et al., 2010; Riva et al., 2009; Sundquist et al., 2011).

Achieving 30 minutes walking

The health impact of relationships between built environments and walking are important because if relationships exist this may have policy implications for urban design, (DoH, 2011) an issue that was discussed in Chapter 3. The Department of Health (DoH) recommends that one way to achieve this is to do 30 minutes moderate-intensity aerobic activity such as cycling or fast walking on at least five days per week in bouts of at least 10 minutes. Therefore, walking outcome number 3 in Table 21 measures if people did 30+ mins brisk/fast walking in the past 4 weeks in bouts of at least ten minutes, can be considered to contribute to meeting recommended PA targets. This variable is derived from the SHeS variable that asks people on how many days in the previous four weeks they did 30+ mins brisk/fast walking in bouts of at least ten minutes. Responses to this continuous variable ranged from 0-28. This was converted to a binary any/none response so that it could be analysed using logistic regression.

The binary outcomes data were checked to ensure that there was even distribution of responses between the categories to facilitate the logistic regression. The outcomes are shown in Table 22 and all categories contained at least 20% (n=872) of responses.

Table 22 Distribution of respondents' binary walking outcomes for walking in the previous four weeks

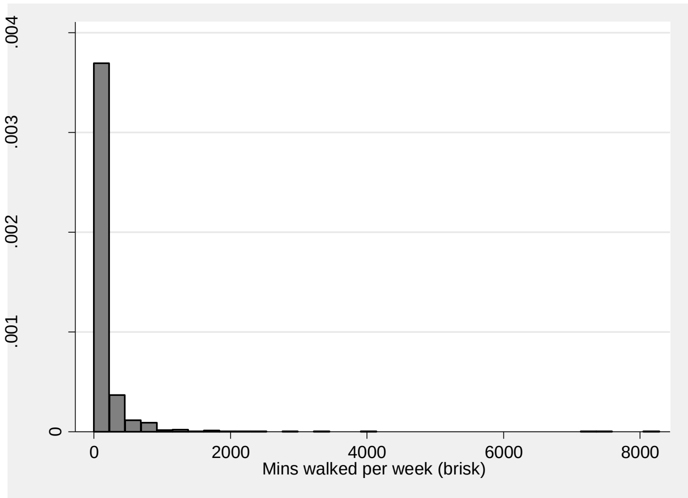
	Freq.	Percent
Any 10+ min walks		
No	872	19.57
Yes	3,584	80.43
More than one 10+ min walk		
No	2,192	49.19
Yes	2,264	50.81
Achieved 30 minutes walking		
No	3,001	67.35
Yes	1,455	32.65
Totals	4,456	100

Average time spent walking per week

The total amount of time spent walking variable was included because this gives an indication of overall walking behaviour which may have a different relationship with any walking, frequency of trips or walking to meet recommendations. It also provides a different type of measure since it is a continuous variable. Measuring total walking is frequently used in other studies (Learnihan et al., 2011; McCormack et al., 2012; Nagel et al., 2008; Owen et al., 2007b; Sundquist et al., 2011; Turrell et al., 2013; Witten et al., 2012). This SHeS variable includes walking in a minimum of 10 minute bouts at a brisk or fast pace and so can also be considered to indicate walking that contributes to meeting government PA recommendations. There were 1,460 respondents who had completed walks of this nature.

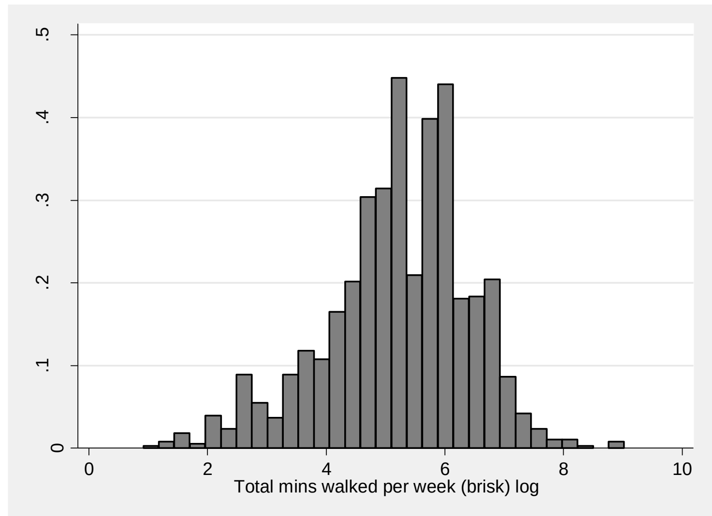
The walking time data were converted from hours to minutes for subsequent modelling convenience. Two assumptions were made in the SHeS derivation of this variable. Firstly, the 'Walking time' category is based on the usual time respondents spent walking each time they walked (the modal value). Secondly, if a respondent said they did more than one walk per day, the number of walks has been assumed to be two walks (SHeS, 2010). The variable was not normally distributed and had a strong positive skew (skewness = 10.63) (Figure 30). Therefore, the log of the data was taken to create a normal distribution suitable for the intended analysis. A histogram showing the logged data is shown in Figure 31. There is a negative skew but the skewness value is close to 1 (-0.53) indicating that the skew is only slight.

Figure 30 Histogram of time spent walking per week (minutes) (n=1,460)



Skewness value: 10.63

Figure 31 Histogram of logged time spent walking per week (minutes) (n=1,460)



Skewness value: -0.53

4.5.2 Sociodemographic covariates

Individual data were collected from respondents from the SHeS. Individual sociodemographic measures were included in the study where they were considered to influence walking behaviour or moderate relationships between built environments and walking. The purpose of including covariates was twofold. Firstly, these were included in the multiple regression analysis of relationships between the built environments and walking to identify associations between AWP and walking independently of the influence of covariates. Secondly, these were used to investigate inequalities in relationships between AWP and walking. Interactions testing was carried out using the AWP measures and sociodemographic covariates to assess the consistency of associations between AWP and walking for different groups of people in different places. The evidence from this analysis was used to inform the analysis of whether associations between AWP and walking were equal in different types of places or for different groups of people, or whether there are variations in relationships.

The covariate variables are listed in Table 23. These were grouped by individual demographic, socio-economic status (SES), and household characteristics. The measure of area deprivation described in Section 4.3.5 is also included as a covariate. The categorisation of the variables facilitated the examination of the strength of influence of different types of factors on walking as well as the individual variables themselves. This will leverage analysis of the results through a socioecological framework which categories different types of influence on behaviour discussed in Chapter 2.

Table 23 Sociodemographic variables included in the analysis of relationships between AWP and walking

Category	**Group**	**Subcategories**
Demographic	*Sex*	Female
		Male
	Age Group	19-29
		30-39
		40-49
		50-59
		60-69
		70+
Individual socioeconomic status	*Economic status*	In employment/education
		Unemployed
		Other
	Employment category	Managerial and professional
		Intermediate
		Routine and manual
		Other
	Qualifications	Degree or above
		Post school
		School
		None
Household characteristics	*Marital status*	Married/civil partnership/ living as
		Not married/civil partnership/living as
		Widowed
	Children in household	No
		Yes
Vehicle access	*Car/van available*	Yes
		No
Area level socioeconomic status	*Area deprivation*	Quartile one (least)
		Quartile two
		Quartile three
		Quartile four (highest)

Demographic factors

Age group and sex were selected for inclusion in the demographic data. Differences in physical activity outcomes and relationships with the built environment have been found for both sex (Boone-Heinonen et al., 2010; Foster and Giles-Corti, 2008) and age (Day, 2008; Forsyth et al., 2009; Nathan et al., 2012). Age is commonly split into approximately ten to fifteen year adult age bands (Badland et al., 2012; Sundquist et al., 2011; Witten et al., 2012). In this study age was split into six groups of ten year age gaps, which was sufficient to detect differences in outcomes.

Individual socio economic status (SES)

In the literature, various indicators are used that can be classified as indicators of individual socioeconomic status. Household income is frequently included (Badland et al., 2012, Learnihan et al., 2011, Owen et al., 2007, Sundquist et al., 2011, Van Dyck et al., 2010, Witten et al., 2012). However, in the study sample, 14% (n=647) of respondents answered 'don't know' or refused to answer the question about household income. Excluding these records was considered to result in the loss of valuable data. Instead, alternative indicators were selected; occupational status, employment category and educational attainment, all of which are used in other studies.

Occupational status was derived from a SHeS variable that asks respondents to choose from a list of occupational categories when asked 'Which of these descriptions applies to what you were doing last week, that is in the seven days ending (date last Sunday)?' (The Scottish Government 2010b) The employment status categories from the SHeS were consolidated into broader categories in line with previous literature; these categories are shown in Table 23. This distinguishes between people who were unemployed (and seeking or intending to seek work) and those who are not working for other reasons, for example, doing unpaid work. This was considered an important distinction since those who are unemployed would be considered at an economic disadvantage compared with those who chose not to work. Additionally, the category of in education/training was included because this group is not economically active and is, therefore, considered distinct from people who are in employment.

The National Statistics Socio-economic Classification (NS-SEC) classifies occupations according to skill level and skill content (ONS, 2010) and was used to develop a measure of occupational status for use in this research. In the literature this variable is measured as, for example, managers and professionals, white collar, blue collar or not easily classified (Turrell et al., 2013) and blue collar or white collar (Van Dyck et al., 2010). In line with the broader categories used in the literature, the NS-SEC 3 category classification was used which classifies people as working in managerial and professional occupations, intermediate occupations, routine or manual occupations. People not in work (for example if they are retired or not currently employed) are classified by their last main job. The main exceptions to this rule are full-time students, the long-term unemployed and people who have never worked (ONS, 2010). These people were allocated to the 'other' category. Educational attainment was included as a SES indicator, which has been used as a covariate in numerous other studies (Berke et al., 2007; Boone-Heinonen et al., 2010; Forsyth et al., 2009; Freeman et al., 2013). The SHeS data on educational attainment were classified into five categories; degree or higher, HNCD or equivalent, higher grade or equivalent, standard grade or equivalent, other school level, no qualifications. For the analysis, the school level qualifications were combined resulting in a total of four educational categories; Degree or above, post-school (higher grade or equivalent), school level (standard grade or equivalent, other school level) and no qualifications.

Household characteristics

Marital status is considered to have a substantial impact on lifestyle and therefore, conceivably, walking behaviour and is often included as a covariate in studies of relationships between built environments and walking (for example, Nathan et al., 2012; Sundquist et al., 2011; Witten et al., 2012). People were classified as being married/in a civil partnership or living as one of the former, not married/in a civil partnership or living as one of the former or widowed. The presence of children in the household was considered an important variable to include because living in a household with children is likely to have an impact on lifestyle factors such as walking behaviour (Cao et al., 2006). The data were categorised in the same way as Owen et al. (2007) into a binary category of whether or not there were children under 16 years of age living in the household. Finally, vehicle access is considered an important covariate as this potentially a pivotal influence on decisions about walking (Panter and Jones, 2010; Turrell et al., 2013) and so data on whether respondents had access to a vehicle or not were included as a covariate.

4.6 Analytical strategy for investigating relationships between AWP measures and walking outcomes in urban Scotland

4.6.1 Introduction

Once the appended dataset received back from the SHeS team, the inclusion/exclusion criteria shown in Table 24 were applied to the dataset. This study focuses on adults and it is typical in the literature to use a minimum age threshold of between 18 years (for example, McCormack et al., 2012) to 20 years (Badland and Schofield 2005) in studies of adults' walking. For the purposes of this study those under 19 years were excluded since Scottish secondary education can last up to the age of 18 years (The Scottish Government 2003a) and so this was deemed an appropriate cut-off age. Respondents were excluded if they experienced claudication (pain when walking) because this is likely to affect their decisions about walking independently of AWP and so and could bias the outcomes. Claudication refers to leg pain when exercising, including walking, and is considered to influence choices about walking. It is likely that people who experience claudication are influenced differently by their environment as their needs are different from people who do not experience claudication. For example, the importance of places to sit and rest may be particularly important to this group (Mays & Regensteiner 2013). To do justice to understanding interrelationships between the built environment and walking behaviour among this group would require specialised consideration and adjustment of the research and methodology. However, people who experience claudication affects just a small percentage of the population (2.3% in 2010 (Bromley et al. 2011)). As such, to include the needs of this group was considered beyond the scope of this project. Finally, respondents who did not provide data on the walking outcomes were deleted. The final dataset comprised 4,456 Scottish adults aged 19-95 years. The sample was cross checked against the complete Scottish Health Survey data (not that which was appended to the AWP dataset) for people who met the same inclusion/exclusion criteria. The sociodemographic characteristics of the sample and the SHeS respondents matched with all differences in sample distribution being less than 1% showing that the sample was representative of this subsection of the Scottish population.

Table 24 Inclusion/exclusion criteria for Scottish Health Survey respondents in the study

Inclusion	**Exclusion**
19 years of age or over	Under 19 years of age
Able to walk without claudication	Experienced any claudication when walking
Provided a response to all questions relating to walking and demographic variables included in the study.	Missing response for any questions relating to walking and demographic variables included in the study.

4.6.2 Analysis

There were three steps to the analysis of relationships between AWP and walking.

1. Bivariate analysis between AWP and each of the walking outcomes were investigated using both study site size zones. Bivariate analysis between the covariate measures with each of the walking outcomes.

2. Regression modelling to determine whether relationships remained when controlling for individual demographic, SES, household characteristics and area deprivation characteristics.

3. Interactions testing was carried out to examine whether there were inequalities in relationships between AWP and different groups and in different levels of area deprivation.

All analyses were carried out using STATA data analysis and statistics software. The Scottish Health Survey (SHeS) contains a weight variable (int10wt) which weights the SHeS data so that they reflect population estimates for health boards by age and sex, this weighting was applied to all analyses so that it accounted for this adjustment. The distribution people within the AWP measure quartiles was considered to ensure that there were adequate numbers in each quartile to carry out the proposed analysis. This is shown in Table 25 which showed that the respondents were evenly distributed between the quartiles, with between 23% – 28% within each quartile. This meant that there were adequate numbers of respondents in each category to carry out the proposed analysis.

Table 25 Percentage distribution of respondents by AWP measure quartiles in 1000m and 500m buffer zones

Quartiles	Destination accessibility		Residential density		Intersection density		Walkability	
	1000m	**500m**	**1000m**	**500m**	**1000m**	**500m**	**1000m**	**500m**
1 (lowest)	26.03	26.37	26.37	25.76	25.22	24.30	25.27	24.35
2	26.08	26.35	26.35	26.57	23.18	25.22	25.61	25.58
3	25.34	24.10	24.10	24.28	25.31	24.26	26.03	26.84
4 (highest)	22.55	23.18	23.18	23.38	26.28	26.21	23.09	23.23

Regression modelling for binary walking outcomes

There were three binary walking outcomes:

1. Whether people had done a walk of at least ten minutes in the previous four weeks
2. Whether people had done more than one walk in the previous four weeks
3. Whether people had walked meeting physical activity recommendations on any day in the previous four weeks.

Logistic regression can be applied to binary outcomes to calculate the likelihood of achieving one outcome over the other (Marsh and Elliot, 2008). Logistic regression was therefore carried out to obtain odds ratios for the likelihood of doing a walk for each AWP measure quartile. Base categories for the AWP measure quartiles were quartile 1 (lowest prevalence of the measure) for all AWP measures and the likelihood of achieving a positive walking outcome in the other AWP quartiles was calculated. Quartile 1 was selected as the base category.

Multiple logistic regression modelling was carried out including sociodemographic variables to see whether relationships remained when controlling for these variables. Due to potentially strong correlations between intersection density, residential density and destination accessibility, the measures that were not being used as the predictor variable were also controlled for in the analysis. The sociodemographic variables were added by variable type, to compare the influence of different types of variables on the strength of the relationships observed. The sociodemographic measures were added to the models in the following order:

1. Individual demographic variables:
    - age group
    - sex
2. Socio economic status (SES) variables:
    - economic status
    - employment category
    - qualifications
3. Household characteristics
    - marital status
    - presence of children in the household
    - vehicle access
4. Area level deprivation

The base categories for the socio-economic groups were the largest group (for example females were chosen because there were a higher number of females than males). Where there were more than two groups (e.g. age group) the largest group at one end of the scale was chosen (for example the youngest age group was chosen). The exception to this rule was in the case of area deprivation where quartile 1 (lowest deprivation) was chosen as the base category for consistency with the AWP measures although there were slightly more (n=1,229) in the highest deprivation quartile than the lowest (n=1,100). Changes in odds ratios for likelihood of achieving a positive walking outcome were observed after the addition of each group to ascertain the influence of each type of covariate on walking outcomes.

Regression modelling for continuous walking outcome variable

There was one continuous walking outcome variable used:

1. Average weekly walking minutes of brisk or fast walking for walks of at least ten minutes

Dummy variables were created for the AWP measure quartiles using quartile 1 (lowest) as the base category. Regression coefficients therefore show predicted change between the base category with the other categories. The logged regression coefficients were converted to 'percentage change' according to the formula (e^b-1) x 100 where *b* is the coefficient and *e* is the natural log (2.71828) (Allison 1999).

Linear regression was carried out to test for relationships between logged minutes walked with AWP variables controlling for sociodemographic and AWP measures. The linear regression used the same modelling strategy as in the logistic regression and base categories for the demographic and socioeconomic measures were set as per the logistic regression. Regression diagnostics tests were applied. A normal PP plot of the predicted values against the observed values to ensure that the residuals were randomly distributed and Cooks distance score was used to check that outliers did not have an undue effect on the magnitude of the regression coefficients (Allison 1999). Tolerance statistics were used to check for multicollinearity.

4.7 Examining inequalities in associations between AWP and walking

A key aim of this thesis is to examine inequalities in relationships between AWP and walking outcomes between different groups of people. While sociodemographic or area level factors are often 'controlled for' in this type of research, it is less common to investigate the influence of such factors on the results. Calls have been made for greater consideration of their influence to enhance understandings of inequalities in relationships between built environment measures and walking (Panter and Jones, 2010). Interactions testing can be used to test if the relationship between two variables is influenced under different conditions (Allison, 1999). It can be used to calculate variation in relationships between AWP and walking when sociodemographic variables are varied. Interactions testing was carried out to test whether the associations between each AWP measure with each walking outcome were the same for all groups included as covariates. Significant interactions would indicate that the associations were unequal.

4.8 Conclusion

This chapter has summarised the methodology used to achieve the aims of the thesis. The next two chapters will present the results. Chapter 5 will show the results of the analysis of the sociospatial distribution of AWP measures. Chapter 6 will present the associations between AWP and walking and inequalities found in these relationships.

Chapter 5. The socio-spatial distribution of Area Walking Potential measures associated with walking

5.1. Introduction

The preceding chapter described the creation of four neighbourhood measures of the supportiveness of the built environment for walking, for neighbourhoods across urban Scotland. Scores from three measures - destination accessibility, residential density, and intersection density - were combined to form the fourth measure of walkability. These measures are considered to represent Area Walking Potential (AWP). This chapter will examine the geographic distribution of AWP across urban Scotland. The first section will consider inequalities in AWP measures across Scotland by exploring their pattern and distribution. Area level socio-spatial inequalities in AWP are then considered by area deprivation.

5.2. Summary of Area Walking Potential Measures

5.2.1 Destination accessibility

Neighbourhood-level destination accessibility was measured by calculating pedestrian access to nine categories of destinations. These were education, health, public transport, outdoor space, leisure activities, food retail, general retail (non-food), financial services and employment. Scores were calculated for each neighbourhood from a possible range of 0 (lowest destination accessibility) to 33 (highest destination accessibility). Destination accessibility scores ranged from 0-32.03 in 500m zones and 0-33 in 1000m zones (Table 26). For neighbourhoods delimited using 500m buffer zones from population centroids the median score (11.69) is slightly lower than the mean 12.64, suggesting that slightly more OAs had lower scores than higher scores. However, in neighbourhoods created using 1000m buffer zones from population centroids a median of 21.85 and a mean of 20.91 showed slightly more study sites had higher destination accessibility scores. Higher scores in 1000m zones are expected because destination accessibility is based on the presence and diversity of destinations and there are likely to be more destinations in larger zones. This shows that the measure is sensitive to zone size which highlights the importance of testing the sensitivity of the analyses of walking outcomes to different sized zones.

5.2.2 Intersection density

A measure of intersection density was used to show street connectivity or permeability. This was calculated by dividing the number of true intersections (three turning options or more) by the neighbourhood land area. The land use areas were created using distances of 500m and 1000m from population weighted centroids, resulting in neighbourhood areas of 0.785km^2 and 3.142 km2. The number of intersections ranged from 6.37 to 1044.59 per km2 in 500m zones and 5.73 to 633.44 in 1000m zones. The lower intersection density scores in 1000m neighbourhoods were expected because the neighbourhoods were created around population weighted centroids, where it is likely that there is higher intersection density. The mean scores were higher than the median scores for both neighbourhood zones (191.33 and 161.78 in 500m zones and 159.24 and 138.85 in 1000m zones respectively) showing more areas had high than low intersection density scores showing more negative than positive scores, showing a slightly positive skew.

5.2.3 Residential density

Residential density was calculated using a measure of dwellings per hectare. Scores ranged from 0 – 253.60 dwellings per hectare in 500m zones and 0 - 96.97 dwellings per hectare in 100m zones. Dwelling densities of 100-200 are typical of high density areas in Scotland (Scottish Executive 2001). Higher densities in the 500m zones are expected because neighbourhood areas were created around population weighted centroids and so there are likely to be more people and more dwellings closer to the in the smaller zones. As with street connectivity the mean scores are higher than the median scores for both zones indicating that more neighbourhoods had higher residential densities than lower residential density.

5.2.4 Walkability

Scores for walkability were created by combining standardised scores for destination accessibility, residential density and intersection density, with a weighting of two applied to destination accessibility and street connectivity. Mean and median scores were equal or very similar for walkability indicating that the scores were evenly distributed across neighbourhoods. The scores were based on standardised z scores for the other measures so the actual numerical outcomes were not meaningful, rather this showed ranked scores for the neighbourhoods.

Table 26 Summary of AWP scores in 500m and 1000m zones (n=30,066)

Zone size	BE measure	Minimum	Maximum	Mean	Median
500m	Destination accessibility (per output area)	0.00	32.03	12.64	11.69
	Residential density (per hectare)	0.00	253.60	30.50	24.83
	Intersection density (per km^2)	6.37	1044.59	191.33	161.78
	Walkability (per output area)	-8.31	15.31	0.00	0.00
1000m	Destination accessibility (per output area)	0.00	33.00	20.91	21.85
	Residential density (per hectare)	0.00	96.97	23.36	19.75
	Intersection density (per km^2)	5.73	633.44	159.24	138.85
	Walkability (per output area)	-10.15	15.29	0.00	0.26

Correlations

Correlations between destination accessibility, residential density and intersection density were calculated using Spearman's correlation coefficient which is suitable for testing skewed data. Walkability was not included because it was calculated using the other three measures and so correlation outcomes would be superfluous.

Table 27 Spearman's Rank correlation for destination accessibility, residential density and intersection density measures in two size zones (n=30,066)

	1000m Zones			**500m Zones**		
	Destination accessibility	Residential density	Intersection density	Destination accessibility	Residential density	Intersection density
Destination accessibility	1.00			1.00		
Residential density	0.48	1.00		0.50	1.00	
Intersection density	0.34	0.49	1.00	0.20	0.52	1.00

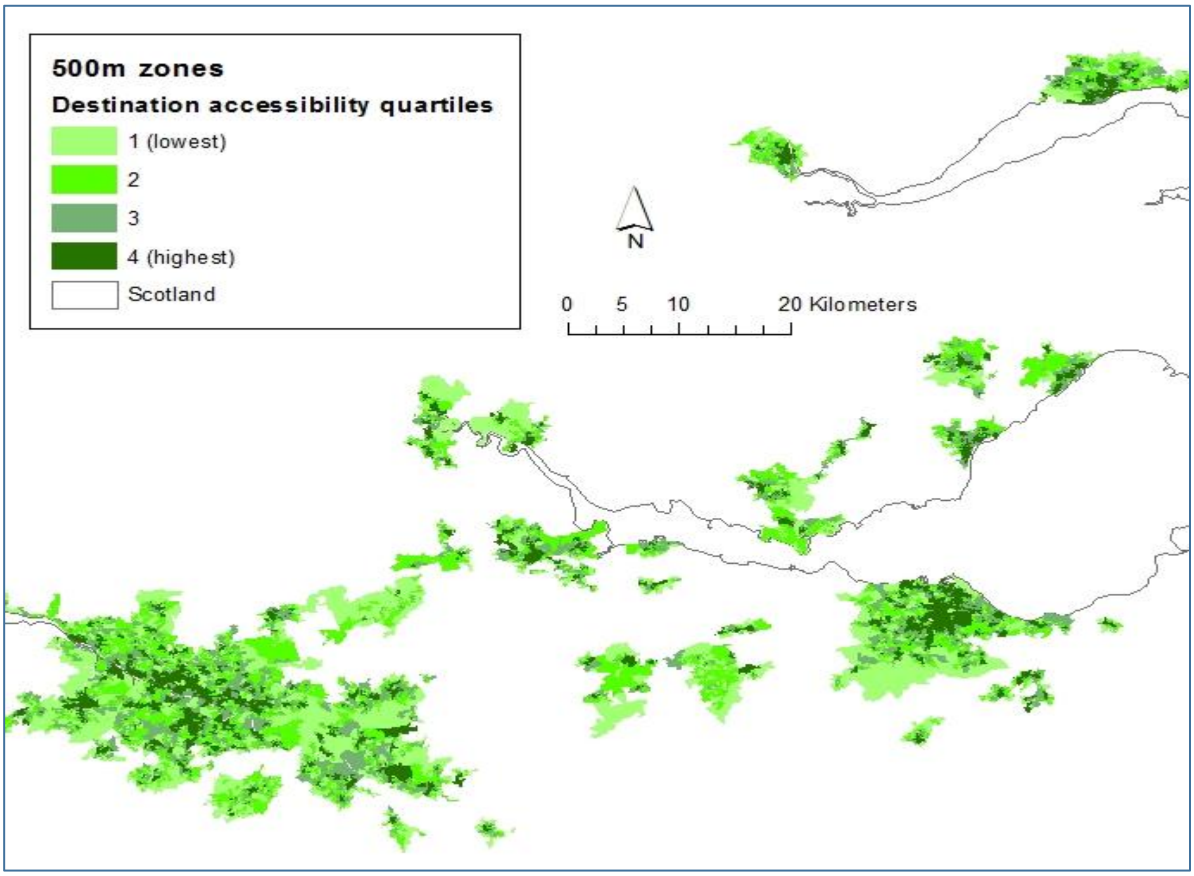
$p<0.001$ for all results

Table 27 shows moderately strong relationships between the walkability components, with correlation coefficients between 0.20-0.52 with all results being statistically significant. This shows that it is moderately likely that people experience similar levels of each of these features of AWP in their neighbourhood. Strongest associations were between residential density and intersection density (0.49 in 1000m zones and 0.52 in 500m zones), indicating that people are more likely to experience higher levels of both these measures. The weakest relationships were between intersection density and destination accessibility (0.34 in 1000m zones and 0.20 in 500m zones) indicating a slightly reduced likelihood of experiencing similar levels of these measures compared with other combinations of AWP features.

5.3 Spatial distribution of Area Walking Potential

Figures 32 to 35 show choropleth maps of destination accessibility, intersection density, residential density and walkability respectively for sections of Scotland. It was not possible to display maps for the whole of Scotland so this section is displayed because it contains the most study sites. Neighbourhoods were assigned a quartile score using AWP measure scores (described in Chapter 4). Shading was used to indicate neighbourhood quartile scores, with darker shades indicating higher quartiles and higher levels of the AWP measure. The neighbourhoods formed contiguous clusters within settlements. Within these, there were observable spatial trends showing unequal distribution of AWP measures. There was evidence of clustering of neighbourhoods with high AWP concentrated in certain areas, surrounded by neighbourhoods with lower AWP. This means that people living in neighbourhoods with low or high access to destination accessibility, intersection density, residential density and walkability were more likely to be surrounded by neighbourhoods with similar levels of these features, making access geographically unequal. In larger settlements, such as Glasgow, there were numerous clusters of high AWP, smaller settlements groups had fewer clusters. The size of clusters varied, with larger clusters in larger settlements. These patterns suggest more people living in larger settlements had higher AWP than people living in smaller settlements. Patterns of clustering were similar for all four AWP measures and in neighbourhoods delimited using both 500m and 1000m zones, which is consistent with the correlation analysis which showed that the AWP measures were associated with each other.

Figure 32 Geographical distribution of destination accessibility score quartiles for 500m and 1000m neighbourhoods across the central belt of Scotland (n=30,066)



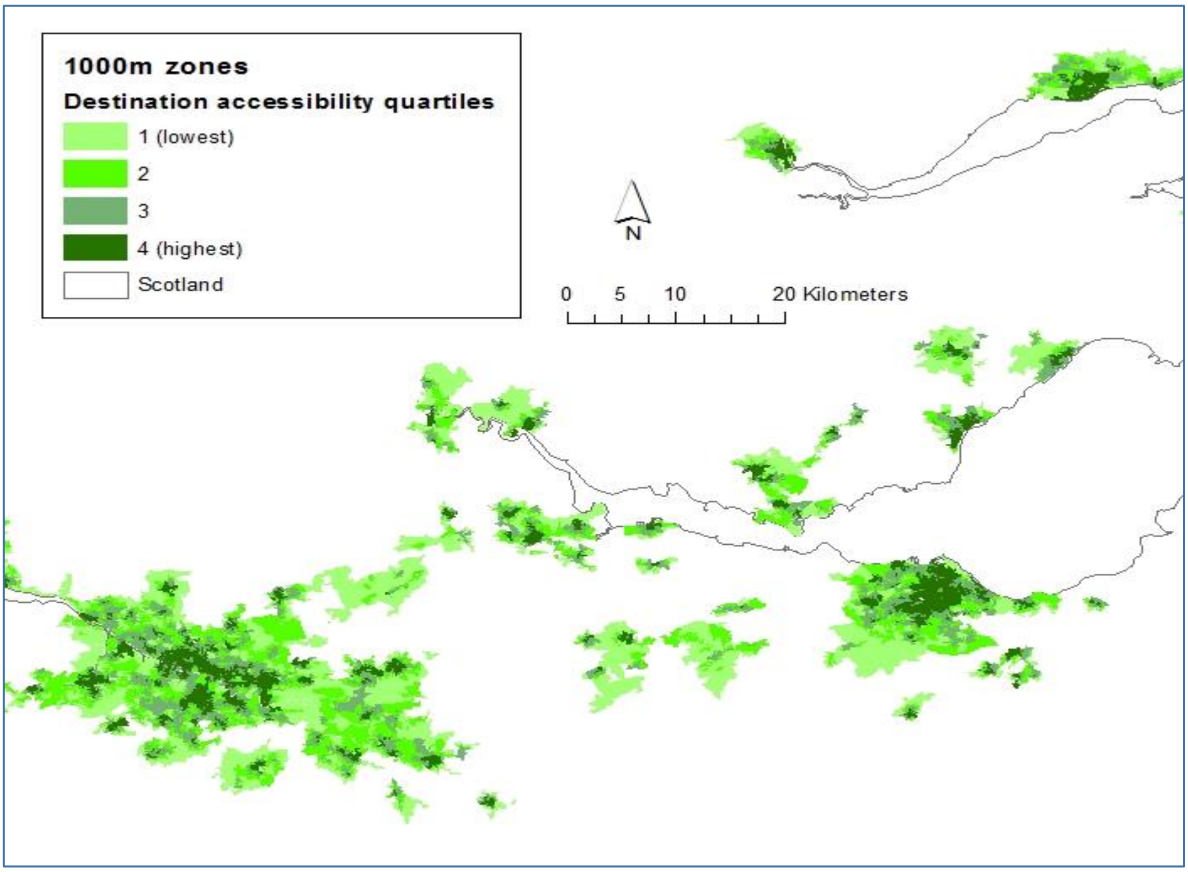


Figure 33 Geographical distribution of intersection density score quartiles for 500m and 1000m neighbourhoods across the central belt of Scotland (n=30,066)

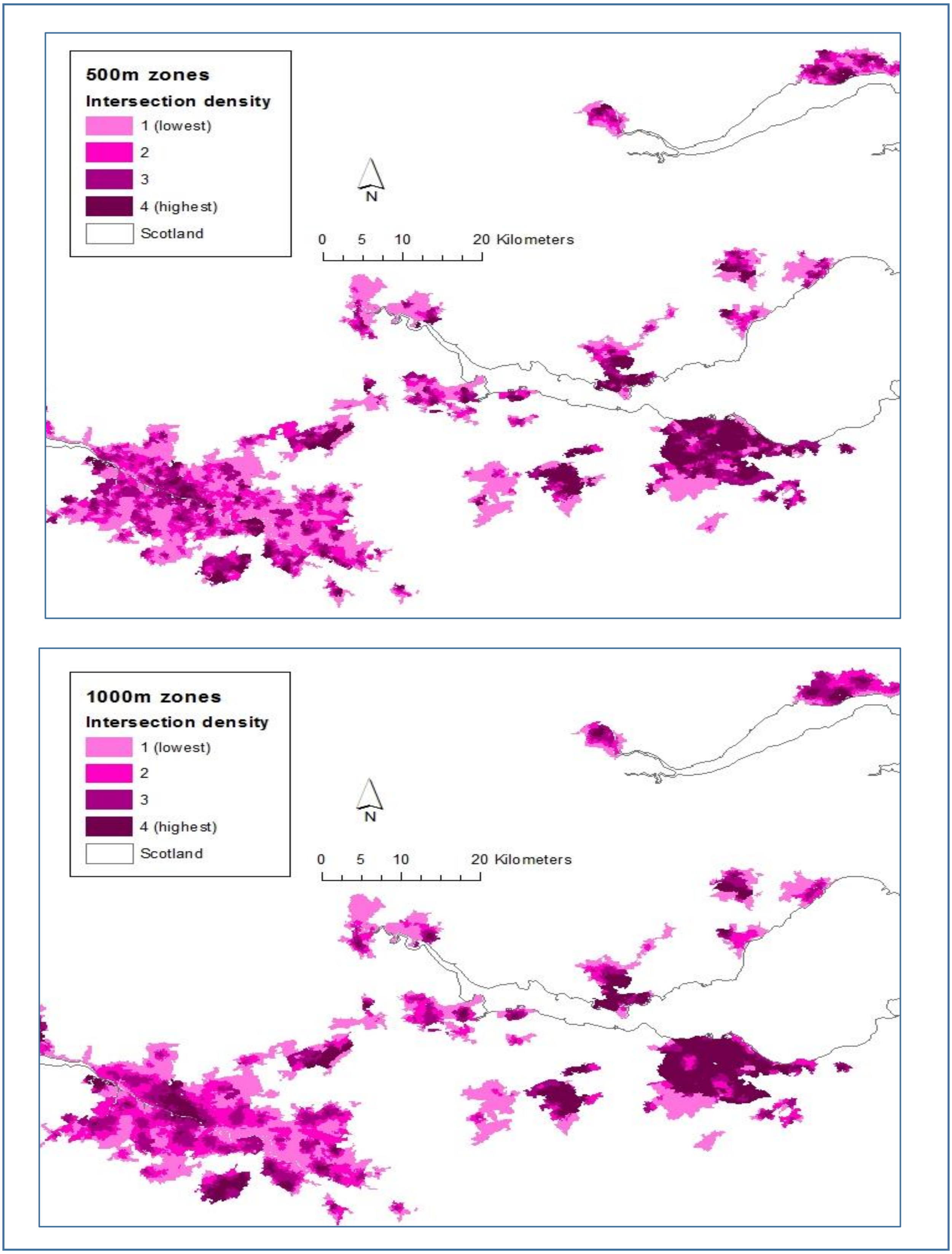


Figure 34 Geographical distribution of residential density score quartiles for 500m and 1000m neighbourhoods across the central belt of Scotland (n=30,066)

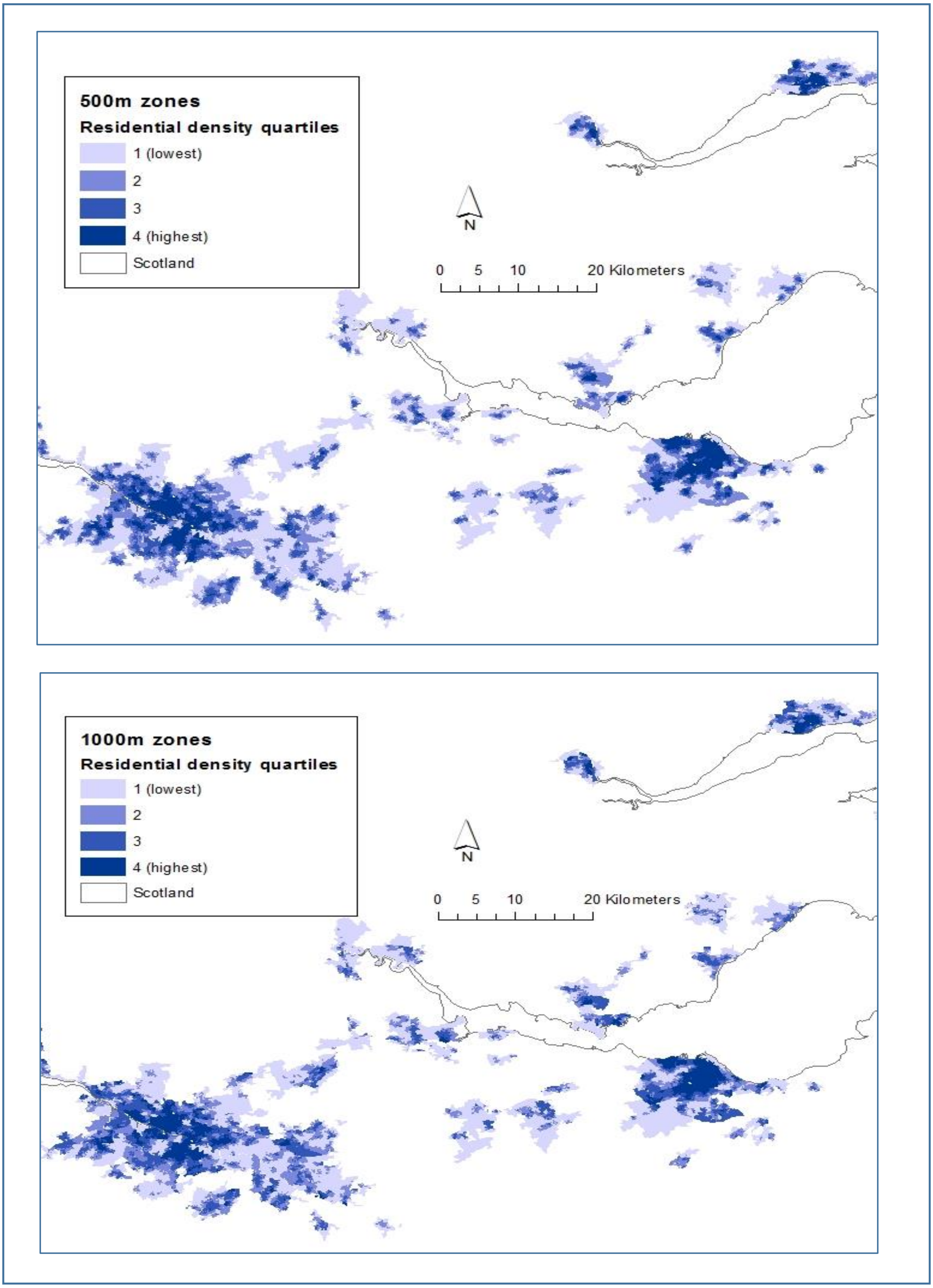
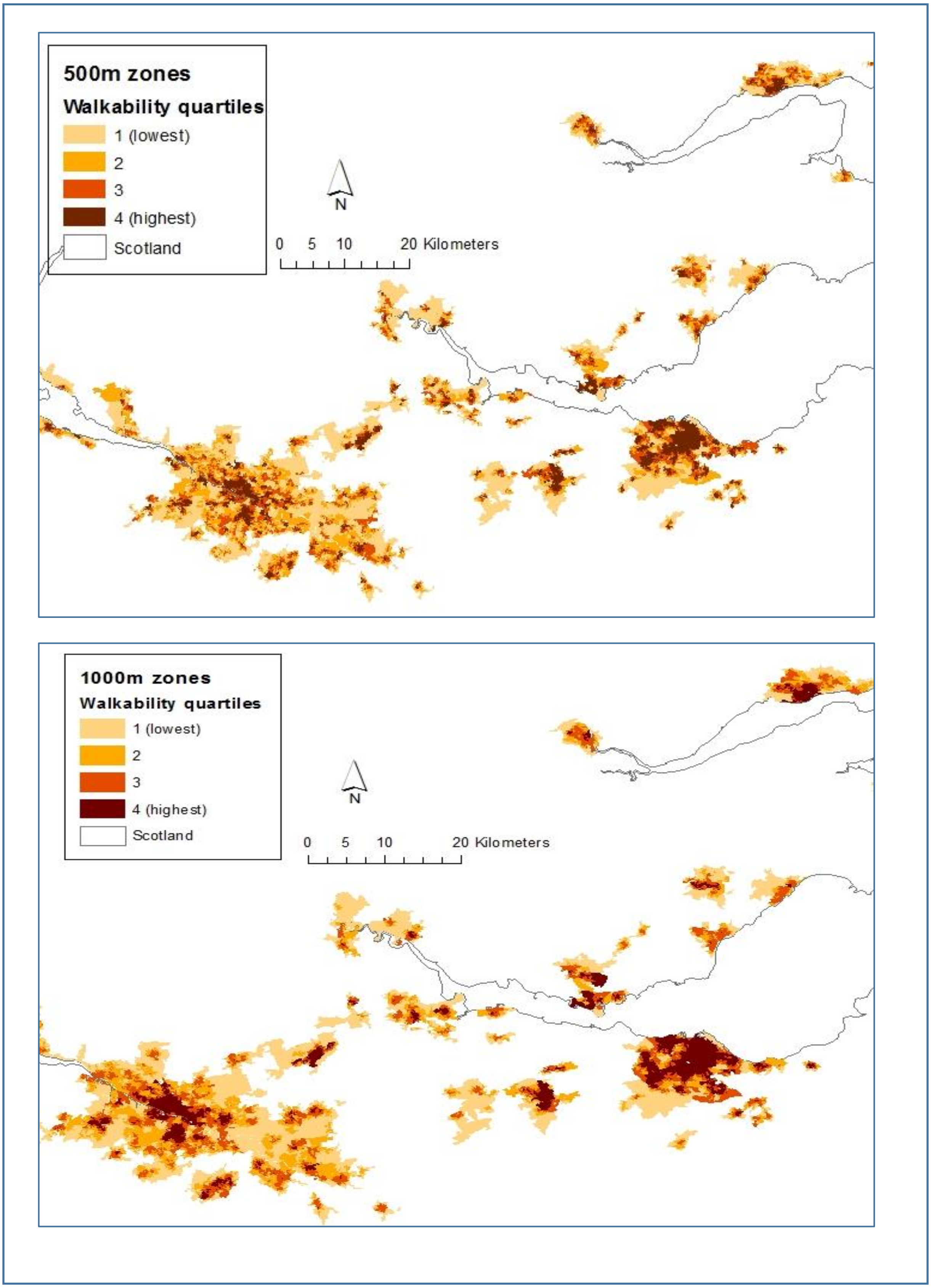


Figure 35 Geographical distribution of walkability score quartiles for 500m and 1000m neighbourhoods across the central belt of Scotland (n=30,066)



The extent of clustering was analysed using Getis Ord General G statistic (G(d)) analysis. High positive Z scores suggest clustering of high values or a hot spot, while a cluster of high negative Z scores shows a cluster of low values. Spatial relationships between output areas were conceptualised using inverse Euclidean distances between output areas, so that neighbouring output areas had a larger influence on the calculation than those that were far away. No threshold distance for a cut off for the inverse distance calculation was applied. Clustering statistics were calculated for Scotland's two largest cities: Glasgow and Edinburgh. These areas were selected because they contain the highest number of output areas in the sample and the largest proportion of the sample. In both cities, the results show high clustering of high scores for all measures which are summarised in Table 28. All four AWP measures displayed statistically significant clustering. In Edinburgh, clustering was highest for residential density closely followed by destination accessibility. In Glasgow, the measure displaying highest clustering was also residential density, but in Glasgow there was greater clustering of intersection density than destination accessibility. In Edinburgh, the measure displaying least clustering was intersection density. In Glasgow, the measure with the lowest clustering was intersection density using 500m neighbourhood zones but destination accessibility using 1000m neighbourhood zones.

This shows that residential density is the least equitably distributed and people in neighbourhoods with low residential density are least likely to be proximal to areas with higher density. Conversely street connectivity and destination accessibility appear to have slightly less inequitable distribution, although all AWP measures displayed significant clustering. This analysis also shows that spatial distribution of AWP measures considered to have the potential to support walking varies between different areas and different types of area. Clustering was slightly higher in 1000m neighbourhoods than 500m neighbourhoods for destination accessibility, intersection density and walkability in both cities. This shows that results are sensitive to buffer size and highlights the importance of selecting the most appropriately sized buffer zone. Smaller buffer zones are likely to be more sensitive to microscale variations in environments that may be overlooked when using larger buffer zones. Understanding such patterns of AWP is important for informing policy strategies aimed at increasing walking. By identifying areas with geographically unequal access AWP policies can be more effectively targeted for areas where there is greatest need. These issues are discussed in more detail in Chapter 8 (Conclusion).

Table 28 Spatial clustering statistics for AWP in for 500, and 1000m neighbourhoods in Glasgow and Edinburgh

Area	AWP measure	Zone	Observed general G	Expected general G	Z score
Glasgow	Destination accessibility	500m	0.000275	0.000253	39.96
		1000m	0.000277	0.000253	48.36
	Residential density	500m	0.000275	0.000253	52.28
		1000m	0.000274	0.000253	51.45
	Intersection density	500m	0.00028	0.000253	44.87
		1000m	0.000281	0.000253	56.17
	Walkability	500m	0.000283	0.000253	53.84
		1000m	0.000285	0.000253	62.81
Edinburgh	Destination accessibility	500m	0.000364	0.000317	46.61
		1000m	0.000364	0.000317	54.18
	Residential density	500m	0.000359	0.000317	50.39
		1000m	0.00036	0.000317	50.21
	Intersection density	500m	0.000326	0.000317	20.06
		1000m	0.000328	0.000317	27.67
	Walkability	500m	0.000343	0.000317	38.33
		1000m	0.000341	0.000317	39.8

P< 0.01 for all results

Correlations between the AWP and population density were considered to establish whether the AWP measures were associated with population density. This will also be used to inform the modelling strategy for analysing relationships between the AWP measures and walking discussed in the subsequent chapter. Strong correlations between population density with AWP measures may indicate the potential for a mediation effect because AWP may be a feature of areas with high population density rather than existing independently of population density. Therefore, if strong correlations exist population density will be controlled for in the subsequent analysis.

Population density was calculated for each study OA using 2001 census statistics available from the UK Data Service Census Support (Casweb, 2013). Population density within the OAs ranged from 0.07 to 1523.4 people per Hectare. The data had a mean of

74.08 and a median of 58.22 indicating a non-normal distribution with a negative skew. Therefore Spearman's' correlation coefficient (r_s) was used to compare the strength of associations between the AWP measures and population density (Table 29) because this is suitable for comparing skewed data. All relationships were positive showing that people who live in more densely populated output areas experience higher destination accessibility, residential density, intersection density and overall walkability. As would be expected, strongest relationships were between residential density and population density in both size zones (0.445 in 500m zones and 0.444 in 1000m zones). However, these are measures of different things since the number of dwelling spaces per area (residential density) is a modifiable feature of the built environment that can be influenced by urban design and planning, a key facet of this research. Population density had weaker relationships with destination accessibility and intersection density. Correlation coefficients with destination accessibility were 0.209 and 0.232 in 500m and 1000m zones respectively. For intersection density correlations were 0.266 and 0.261 in 500m and 1000m zones respectively. Walkability showed a moderately strong positive relationship with population density with r_s values of 0.341 in 500m zones and 0.333 in 1000m zones. These results show that areas with higher population density were also likely to have somewhat higher AWP. The strength of the relationships was very similar between the two neighbourhood size zones, showing that the size of the hypothesised walking area does not substantially affect the trends observed. These results suggest that although there were some associations between the AWP measures with population density, these were not so strong as to suggest that associations between the AWP measures with walking could be attributed to population density.

Table 29 Spearman's correlation coefficients (r_s) for relationships between population density and AWP

AWP measure	r_s	
	500m zones	**1000m zones**
Destination accessibility	0.209	0.232
Residential density	0.443	0.444
Intersection density	0.266	0.261
Walkability	0.341	0.333

5.4 Deprivation and Area Walking Potential

Deprivation scores were allocated to neighbourhoods as described in Chapter 4. Higher deprivation scores show areas with higher deprivation. There were weak positive relationships between deprivation and AWP (Table 30), suggesting that more deprived areas typically also had higher AWP, suggesting they were more supportive of walking. Of the AWP measures, the strongest relationship was between deprivation and residential density, which had correlation coefficients of 0.259 and 0.253 in 500m and 1000m zones respectively, this is likely to reflect the higher deprivation found in larger Scottish cities (Transport Scotland 2005; The Scottish Government 2011). The relationship between intersection density and deprivation was negligible being less than 0.1 in both zones. Walkability showed weak relationships at both size zones. Relationships were all slightly stronger in the smaller size zones.

Table 30 Spearman's correlation coefficients (r_s) for relationships between deprivation and AWP

AWP measure	r_s	
	500m zones	**1000m zones**
Destination accessibility	0.191	0.178
Residential density	0.259	0.253
Intersection density	0.048	0.019
Walkability	0.194	0.176

- p<0.01 for all results
- Higher deprivation scores indicate more deprived neighbourhoods, therefore positive rs values indicate a positive relationship between the AWP measures and increasing deprivation
- AWP scores were created using 500m and 1000m measures around output area centroids; deprivation scores apply to entire output areas.

However, comparing the mean scores for AWP measures within deprivation quartiles showed a more nuanced picture (Table 31). Scores were lowest in areas with the lowest deprivation (i.e. the most affluent places) for all measures, except for intersection density measured using 1000m zones where scores were slightly lower in quartile 4 (highest deprivation). This shows that in general people living in the most affluent areas had worse AWP. Mean scores for destination accessibility and residential density scores showed small incremental increases with increasing area deprivation. Destination accessibility (measured within 500m zones) was over 10% higher in the most deprived neighbourhoods compared with the least deprived, increasing from 10.36 (95% CI 10.20-10.51) to 13.63 (95% CI 13.48-13.78). There was an increase of over 12% measured using 1000m zones, with mean scores of 18.25 (95% CI 18.06-18.43) in deprivation quartile 1 to 22.31 (95% CI 22.17-22.44) in quartile 4. Mean residential density scores increased by 2% from18.92 (95% CI 18.61-19.24) to 23.88 (95% CI 23.62-24.14) between deprivation quartiles 1 and 4 using 500m zones and by 4.9% between the same measured using 1000m zones, with an increase from a mean of 20.22 (95% CI 19.93-20.51) in quartile 1 to 25.01 (95% CI 24.77-25.25) in quartile 4. Thus, there were small increases in residential density and destination accessibility as area deprivation increased. Mean intersection density scores did not show consistent relationships;

scores were higher in the two middle deprivation quartiles and lower in the highest and lowest quartiles in both size zones. Walkability scores reflected the relationships observed for destination accessibility and residential density, with low mean scores in the quartile containing lowest deprivation output areas, and similarly higher scores in the other three quartiles. However, with walkability there was no consistent increase in mean scores in the higher three deprivation quartiles, in 500m zones scores were -1.18 (95% CI -1.27 - -1.10), 0.33 (95% CI 0.24 – 0.42), 0.58 (95% CI 0.50 – 0.66) and 0.28 (95% CI 0.20 – 0.35) in deprivation quartiles 1 to 4 and -1.08 (95% CI -1.18 - -0.98), 0.28 (95% CI 0.19 – 0.38), 0.49 (95% CI 0.41 – 0.58) and 0.30 (95% CI 0.24 – 0.37) in 1000m zones. Thus, walkability scores did not show consistent variation by deprivation, but scores were higher in the two highest deprivation quartiles and lower in the lowest deprivation quartile. These trends were very similar for both neighbourhood sizes.

Table 31 Mean AWP measure scores within area deprivation quartiles for 500m and 1000m zones

Deprivation quartile	Destination accessibility			Residential density			Intersection density			Walkability		
	Mean	(95% CI)		Mean	(95% CI)		Mean	(95% CI)		Mean	(95% CI)	
500m zones												
1 (lowest)	10.36	(10.20-	10.51)	18.92	(18.61-	19.24)	173.75	(171.36-	176.13)	-1.18	(-1.27-	-1.10)
2	12.95	(12.79-	13.12)	22.96	(22.58-	23.34)	202.62	(199.85-	205.39)	0.33	(0.24-	0.42)
3	13.62	(13.47-	13.78)	23.29	(22.95-	23.62)	204.45	(201.68-	207.22)	0.58	(0.50-	0.66)
4 (highest)	13.63	(13.48-	13.78)	23.88	(23.62-	24.14)	184.52	(181.99-	187.05)	0.28	(0.20-	0.35)
1000m zones												
1 (lowest)	18.25	(18.06-	18.43)	20.22	(19.93-	20.51)	153.94	(151.82-	156.05)	-1.08	(-1.18-	-0.98)
2	21.13	(20.96-	21.30)	23.96	(23.62-	24.30)	167.09	(164.95-	169.24)	0.28	(0.19-	0.38)
3	21.94	(21.79-	22.09)	24.25	(23.95-	24.55)	165.83	(163.71-	167.95)	0.49	(0.41-	0.58)
4 (highest)	22.31	(22.17-	22.44)	25.01	(24.77-	25.25)	150.11	(148.42-	151.80)	0.30	(0.24-	0.37)

Figures 36 to 39 show the distribution of AWP measure quartiles within deprivation quartiles to show counts of each neighbourhood within deprivation quartiles. The numbers of output areas in the highest destination accessibility and residential density quartiles increased as deprivation increased, and the numbers in the lower quartiles decreased, but these trends were more marked in the lowest deprivation quartile. As deprivation increased, the number of neighbourhoods with lowest walkability decreased from 3154, 1841, 1284 to 1238 in deprivation quartiles 1 to 4 in 500m zones and 3140, 1812, 1353 and 1212 and 1000m zones. However, there was little evidence of a consistent relationship between neighbourhoods with high walkability score quartiles and deprivation, the number of output areas in the highest quartiles was highest in deprivation quartiles 2 and three and lower in deprivation quartiles 1 and 4. Gamma tests of association showed that the positive relationship between deprivation quartiles and AWP was strongest for residential density with weak relationships for destination accessibility and walkability. The relationship between intersection density and deprivation was negligible (Table 32). The results were very similar for both size zones. Overall there was a consistent trend of lower AWP in areas with lower deprivation, showing that people living in the most affluent areas tended to have lower neighbourhood AWP. These results were not sensitive to neighbourhood size zone.

Figure 36 Distribution of destination accessibility quartiles within deprivation quartiles in 500m and 1000m zones (n=30,066)

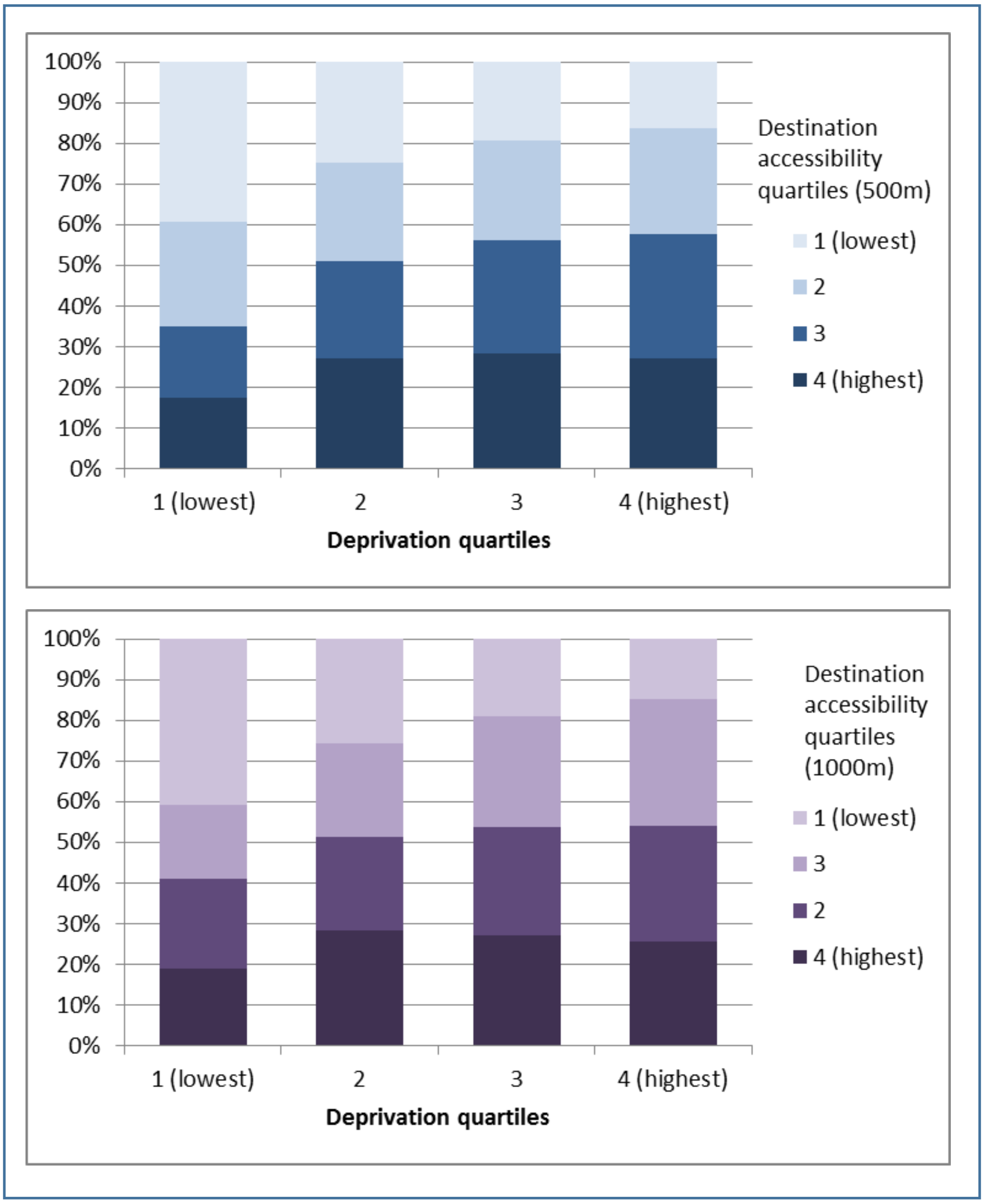


Figure 37 Distribution of residential density quartiles within deprivation quartiles in 500m and 1000m zones (n=30,066 in each size zone)

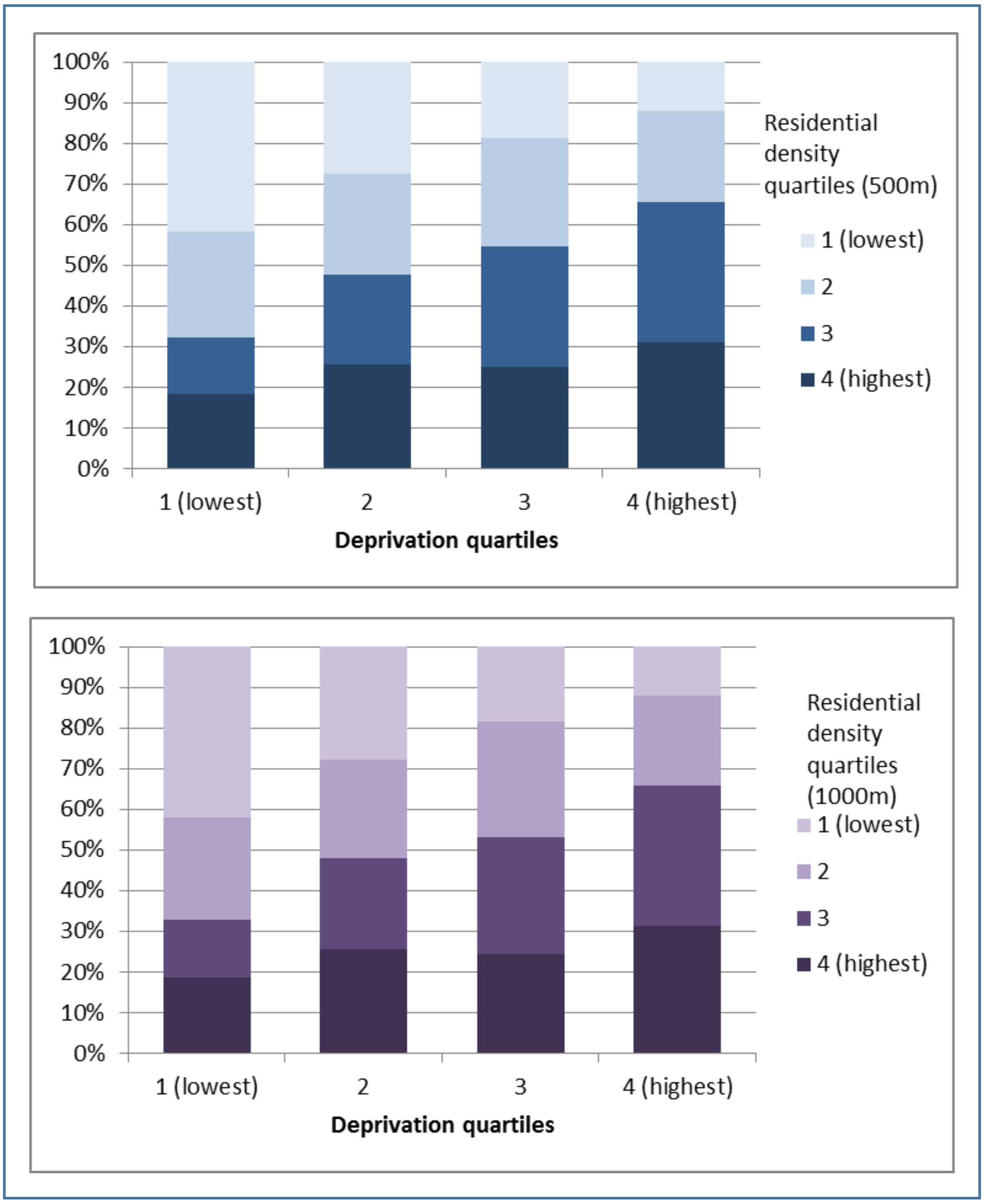


Figure 38 Distribution of intersection density quartiles within deprivation quartiles in 500m and 1000m zones (n=30,066 in each size zone)

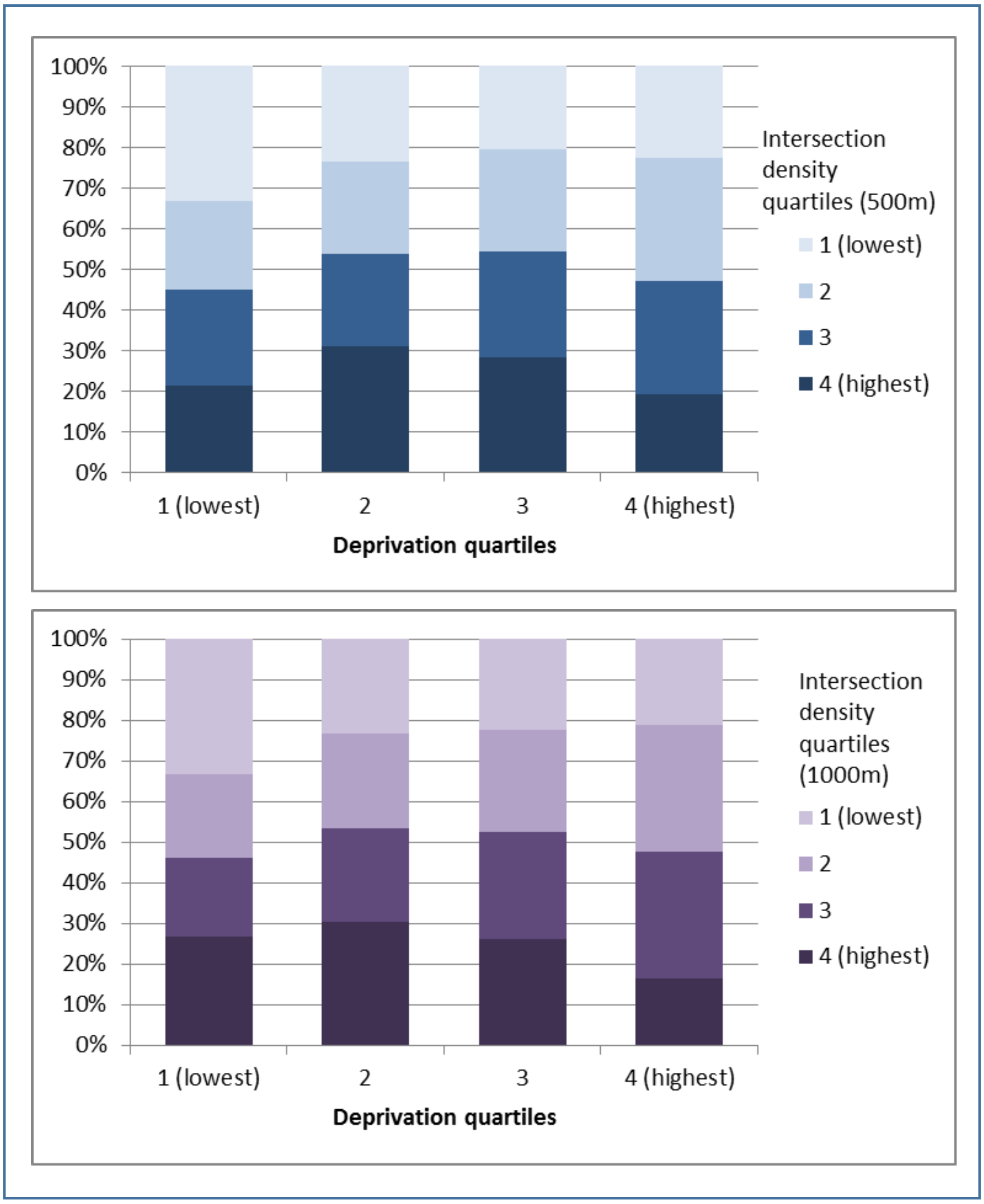


Figure 39 Distribution of walkability quartiles within deprivation quartiles in 500m and 1000m zones (n=30,066 in each size zone)

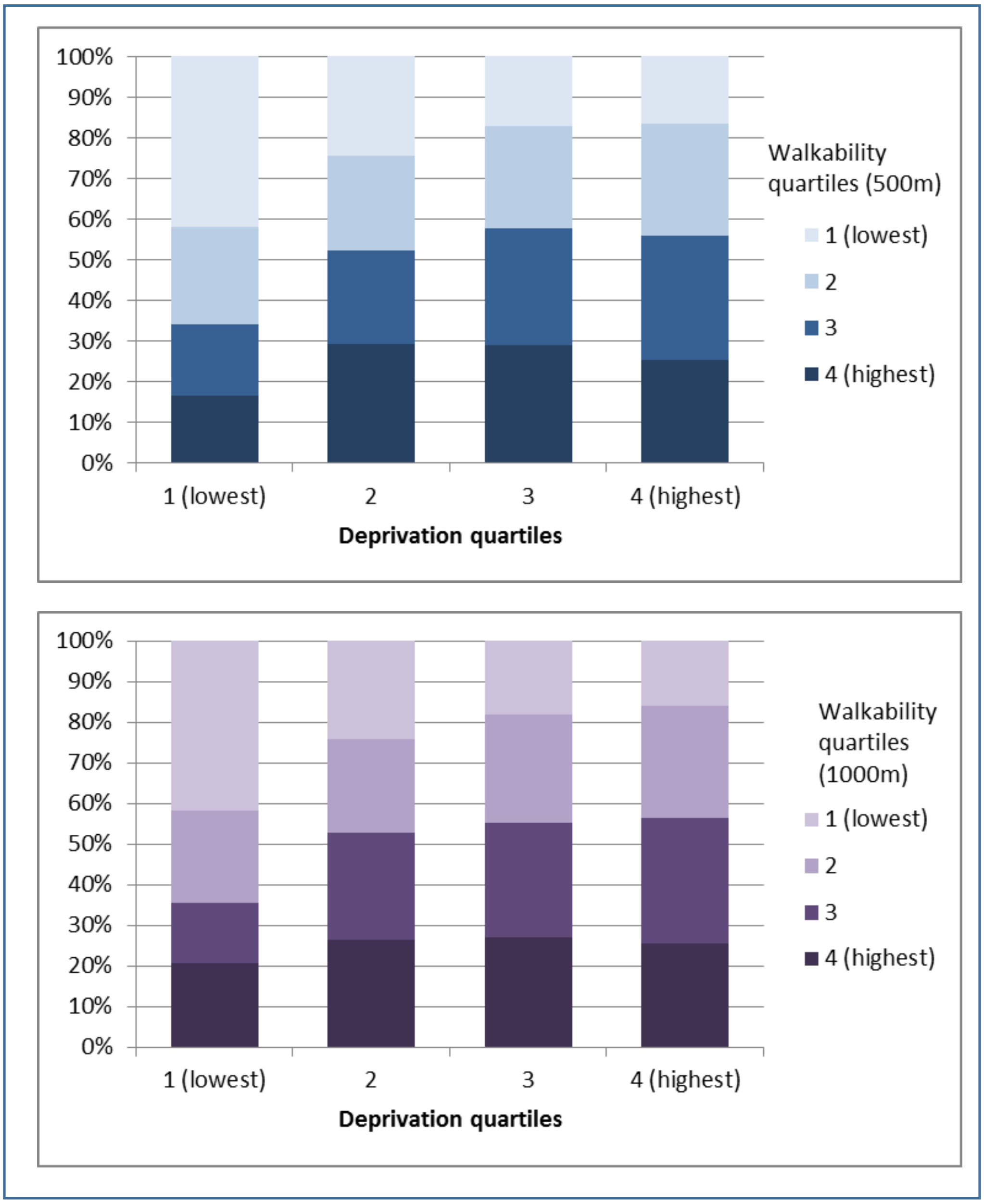


Table 32 Gamma test results for correlation between deprivation quartiles and AWP in 500m and 1000m zones (n=30,066 in each zone)

AWP measure	Gamma statistic	
	500m zones	1000m zones
Destination accessibility	0.195	0.180
Residential density	0.268	0.265
Intersection density	0.036	0.005
Walkability	0.198	0.178

P<0.01 for all results

5.5 Conclusion

This chapter has shown how the research generated spatial information about the distribution of AWP across urban Scotland. It is the only study to date investigating associations between AWP and deprivation in urban areas across a whole country. Understanding urban form in relation to AWP enables us to understand the pattern of built environments which may influence behaviours such as walking, which may in turn influence physical activity related health outcomes. This type of information is likely to be of interest to policy makers and planners in the fields of urban design, public health and sustainability, and those concerned with inequalities. It can help to support geographically targeted policies aimed at enhancing AWP and benefitting disadvantaged communities through encouraging active travel and reducing carbon emissions by encouraging active travel over motorised transport.

This analysis has shown that spatial distribution of AWP measures considered to have the potential to support walking is unequally distributed. This is congruent with others studies which have found spatial patterning of AWP measures (Siu et al. 2012; Cowie et al. 2016; Riva et al. 2009). It is possible that these are demarcated by proximity to urban centres and that people living in more central urban districts have disproportionately high access compared with people living in more peripheral areas. This is likely to be because of the way in which urban areas develop, typically a central hub with shops and services which grow outwards. By contrast suburban areas were designed to provide housing, often for people who desired to live away from the city centre and closer to countryside (Whitehead 2008) with a focus on providing a spacious, quiet and safe environment rather than having high AWP. The impact of this is that urban residents have geographically unequal access to environments that are considered to support walking.

Patterns of physical activity differ by area deprivation and previous work has suggested that this might be partly attributable to variations in the built environment. This study compared AWP by area deprivation and found no evidence of deprivation amplification, whereby people in more deprived areas have worse AWP. Conversely, it showed that people in the more affluent areas had worse walking environments, and people living in areas with high deprivation did not experience low AWP. These results indicate that people living in more urban and less wealthy neighbourhoods are likely to experience high AWP, while their counterparts in wealthy suburban neighbourhoods have low AWP. There were differences in associations for the different measures, with strongest associations for residential density followed by destination accessibility, whereas associations with intersection density were negligible indicating that this measure was more equally dispersed.

Chapter 6. Relationships between Area Walking Potential and walking

6.1. Introduction

In the previous chapter, the geographical distribution of Area Walking Potential (AWP) across urban Scotland was examined. The next step is to present the results of the analysis between the measures of AWP with the walking behaviour of residents in urban Scotland. This chapter will address the following thesis aims:

- To investigate relationships between the measures of the built environment and walking behaviour of residents in urban Scotland.
- To identify inequalities in relationships between the built environment measures and walking for people with different sociodemographic characteristics (such as age and individual socioeconomic status) and for people living in different types of area.

Initially, the study sample is summarised. Using data from the 2010 Scottish Health Survey (SHeS), the first section (section 6.2) presents descriptive statistics for the study sample and section 6.3 describes the walking outcome measures. Section 6.4 details the covariates included in the analysis of relationships between AWP and walking. Section 6.5 examines and presents associations between AWP and walking. This section addresses the first aim of the chapter using regression modelling to investigate relationships between AWP measures and walking. Finally, section 6.6 examines inequalities in the relationship between AWP and walking for people with different demographic and socioeconomic characteristics or for people living in different area types. Stratified analysis was used to examine differences in outcomes for different groups and the regression models were fitted with interaction terms to test for significance of variations between groups.

6.2 Descriptive statistics for the study sample

The first part of the analysis focused on relationships between AWP and walking behaviour. Neighbourhood geographies were derived based on hypothesised neighbourhood walking zones which were 1000m and 500m buffers around population weighted centroids. Four measures of AWP were created which were destination accessibility, street connectivity, residential density and walkability. A measure of area deprivation was also created for each neighbourhood. Neighbourhoods sites were given a score for each AWP measure and deprivation with higher scores indicating a more of each measure. Neighbourhoods were ranked based on scores for each measure and divided into quartiles where 1 = lowest and 4 = highest levels. A detailed description of the creation of these measures can be found in Chapter 4, Methodology.

The ranked AWP measure scores were sent to the Scottish Health Survey team at Scottish Government. The AWP measure scores were appended to individual-level SHeS data from the 2010 Scottish Health Survey based on area of residence where data were available. The geographic reference for the neighbourhood was then removed to protect the anonymity of the survey respondents. The final study sample comprised 4,456 respondents aged 19 years or older, who lived in areas classified as settlements of over 10,000 people and could walk without claudication. A weighting was applied to the data which meant that these matched the age and sex profile of this section of the Scottish population for the analysis. The SHeS dataset did not contain data for every neighbourhood zone and so there were between 22.5 to 27% of respondents within each quartile. There were, however, no consistent trends in the distribution of proportions between the quartiles, Figures 40a and b show the respondents in the sample were reasonably evenly distributed between the quartiles in both size zones.

Figure 40a Percentage distribution of study respondents by AWP measure quartiles in 1000m zones (n=4,456)

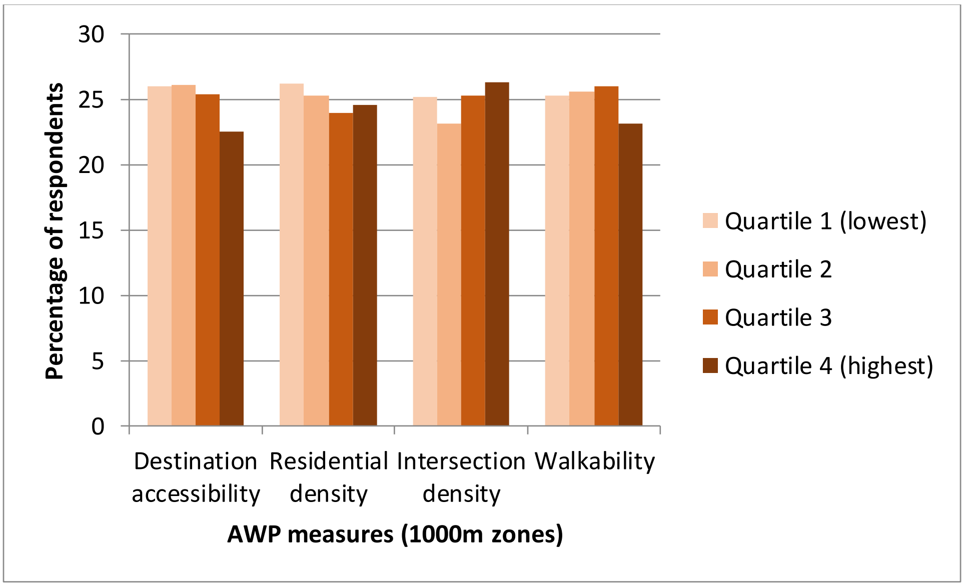
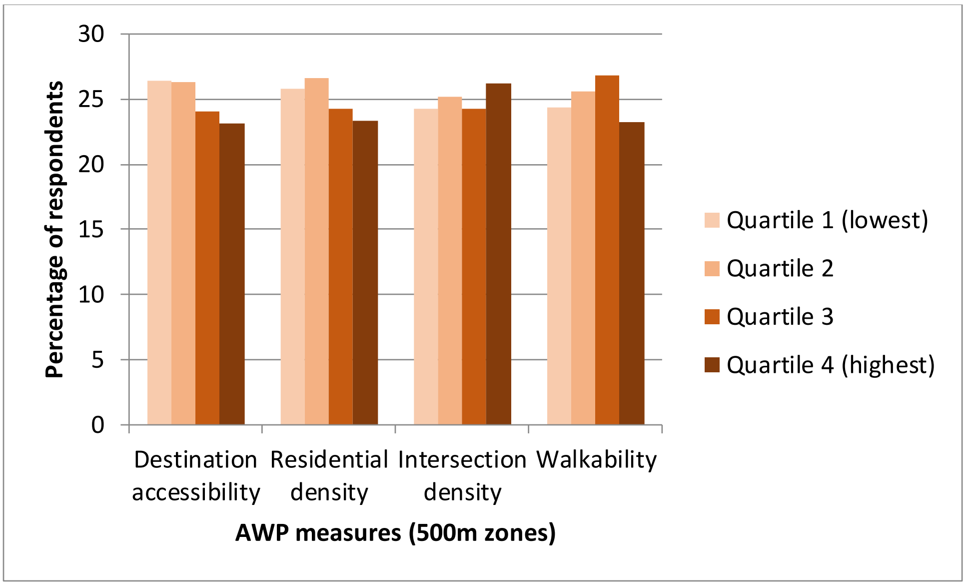


Figure 40b Percentage distribution of study respondents by AWP measure quartiles in 500m zones (n=4,456)



6.3 Walking outcome variables

Four walking outcomes were included in the study which reflected different types of walking behaviours. These were (i) whether people had completed any walks of ten minutes or more in the previous four weeks, (ii) whether they had completed more than one (multiple) walks, (iii) whether they had achieved 30 minutes walking and (iv) the total amount of time they had spent walking briskly in the previous week.

The distribution of respondents' binary walking outcomes is shown in Table 33. The majority (80.43%, n= 3,584) of respondents had completed a walk. A smaller majority (50.81%, n=2,264) had completed multiple walks. Fewer people (32.65%, n=1,455) had achieved 30 minutes walking. There were 1,460 respondents who walked briskly for least ten minutes in the previous four weeks. Table 34 shows weekly walking minutes ranged from 2.5 minutes[3] to 8280 minutes (n=1), equating to 138 hours per week (a mean of 20 hours per day[4]). The median amount of time spent walking was 210 minutes per week (n=67 respondents) which equates to a mean of 30 minutes per day.

[3] Respondents were asked the question if they had walked for at least ten minutes in the previous four weeks. This total was then divided to create an average weekly total, which is why the minimum is less than ten minutes.

[4] This unlikely outcome was queried with the Scottish Government's data team. The response was that it was possible that three of the records included in this analysis had been coded incorrectly. However, in the sample of 1,460 it is unlikely that these records would influence the significance of findings.

Table 33 Distribution of Scottish Health Survey respondents' binary walking outcomes for walking in the previous four weeks (n=4,456)

	Freq.	Percent
Any walks		
No	872	19.57
Yes	3,584	80.43
Multiple walks		
No	2,192	49.19
Yes	2,264	50.81
30 minutes walking		
No	3,001	67.35
Yes	1,455	32.65
Totals	4,456	100

Table 34 Summary statistics for Scottish Health Survey respondents' total minutes walking in the previous week (n=1,460)

	Freq.	Mean	Median	Min	Max
Total mins walking	1460	341.90	210	2.5	8280

The distribution of the susbset of 1460 respondents across the AWP quartiles was checked to ensure that the proposed regression analysis was still valid. Table 35 shows that the respondents were reasonably evenly dispersed between the quartiles. The majority of quartiles held between 22% to 27% of the sample. However, there were a larger proportion of respondents living in intersection density quartile four with 31.03% (n=453) in 1000m zones and 28.63 (n=418) in 500m zones. There were higher proportions of people living in residential density quartile 1 (n=378, 35.89%) in 1000m zones. However, these sample sizes are large enough to mean that the proposed regression analysis was still valid.

Table 35 Distribution of respondents (n (%)) who had walked briskly for at least ten minutes by environment measure quartiles in 1000m and 500m zones (n=1,460)

Quartile	Destination accessibility n (%)		Residential density n (%)		Intersection density n (%)		Walkability n (%)	
	1000m	**500m**	**1000m**	**500m**	**1000m**	**500m**	**1000m**	**500m**
1 (lowest)	390 (26.71)	390 (26.71)	378 (35.89)	362 (24.79)	329 (22.53)	333 (22.81)	366 (25.07)	335 (22.95)
2	358 (24.52)	347 (23.77)	354 (24.25)	394 (26.99)	347 (23.77)	343 (23.49)	353 (24.18)	365 (25.00)
3	342 (23.42)	368 (25.21)	329 (22.53)	326 (22.33)	331 (22.67)	366 (25.07)	348 (23.84)	386 (26.44)
4 (highest)	370 (25.34)	355 (24.32)	399 (27.33)	378 (25.89)	453 (31.03)	418 (28.63)	393 (26.92)	374 (25.62)
Total	1460 (100)	1460 (100)	1460 (100)	1460 (100)	1460 (100)	1460 (100)	1460 (100)	1460 (100)

6.4 Covariate measures

Demographic, socio-economic status (SES), household characteristics and area deprivation measures were selected for inclusion in the analysis where these were considered to potentially influence walking behaviour. The evidence and rationale for their selection is described in Chapter 4 (Methodology). These measures were:

Demographic measures:	Sex
	Age group
SES measures:	Occupational status
	Employment category
	Educational attainment
Household characteristics:	Presence of children in household
	Marital status
	Car access
Area level deprivation:	Area level deprivation (quartiles)

This section will detail descriptive statistics for these variables to show the sample characteristics. It will then examine the influence of demographic, socioeconomic status (SES), household characteristics and area level deprivation on walking outcomes. Where there is evidence of associations, these will be included as covariates in modelling relationships between AWP and walking. Inequalities in relationships will be tested for using interactions testing.

6.4.1 Descriptive statistics of demographic, SES, household characteristics and area deprivation measures

The distribution of the respondents in the sample was compared with the distribution with all SHeS respondents who met the same inclusion and exclusion criteria (see Table 24, Chapter 4, Methodology). This was to ensure that the sample of respondents used in this study (see section 6.2) were representative of the Scottish population. Table 36 shows the samples were closely matched, with all differences being less than 1% apart from in the employment category. There were fewer people in the managerial category in the study sample than in the SHeS sample (a reduction of 4.36%). This is likely to be because of a greater concentration of wealth outside the most urbanised areas of Scotland (Bailey et al. 2016). However, the study sample was similar to the SHeS sample overall and can be considered to adequately represent this subsection of the Scottish population.

Table 36 Study sample (n=4,456) compared with Scottish Health Survey respondents meeting the same inclusion/exclusion criteria (n=4,610)

	Study sample		Scottish Health survey sample		% discrepancy between samples*
	n	%	n	%	
Sex					
Female	2,541	57.02	2,634	57.14	-0.12
Male	1,915	42.98	1,976	42.86	0.12
Age Group					
19-29	688	15.44	699	15.16	0.28
30-39	673	15.1	691	14.99	0.11
40-49	821	18.42	851	18.46	-0.04
50-59	742	16.65	759	16.46	0.19
60-69	761	17.08	791	17.16	-0.08
70+	771	17.3	819	17.77	-0.47
Economic status					
Employment/education	2,399	53.84	2453	53.21	0.63
Unemployed	464	10.41	486	10.54	-0.13
Other	1,593	35.75	1671	36.25	-0.5
Employment category					
Managerial and professional	1,312	29.44	1,558	33.8	-4.36
Intermediate	815	18.29	758	16.44	1.85
Routine and manual	2,143	48.09	2,115	45.88	2.21
Other	186	4.17	179	3.88	0.29
Qualifications					
Degree or above	1,161	26.05	1,194	25.9	0.15
Post school	986	22.13	1018	22.08	0.05
School	1,176	26.39	1210	26.25	0.14
None	1,133	25.43	1,188	25.77	-0.34
Marital status					
Married/civil partnership/ living as	2,704	60.68	2,792	60.56	0.12
Not married/civil partnership/living as	1,354	30.39	1393	30.21	0.18
Widowed	398	8.93	425	9.22	-0.29
Children in household (2-15 years)					
No	3,518	78.95	3,639	78.94	0.01
Yes	938	21.05	971	21.06	-0.01
Car/van available					
Yes	3,046	68.36	3,131	67.92	0.44
No	1,410	31.64	1,479	32.08	-0.44
Area deprivation					
Quartile one (least deprivation)	1,097	24.62	**	**	
Quartile two	1,095	24.57	**	**	
Quartile three	1,037	23.27	**	**	
Quartile four (highest deprivation)	1,227	27.54	**	**	
Totals	4,456	100	4,610	100	

*% discrepancy = sample % - SHeS %

**No data available because this measure was created for the study sample only.

6.4.2 Associations between demographic, SES, household characteristics and area deprivation with walking outcomes

Bivariate regression was used to compare associations between demographic, SES, household characteristics and area deprivation with the four walking outcomes. For the binary walking outcomes (any walks, multiple walks, having achieved 30 minutes walking) logistic regression was used. For total time spent walking linear regression was used. The results are presented in Tables 37 and 38 and described below.

Demographic characteristics

Males were significantly more likely than females to have achieved 30 minutes walking (58% increased odds) but walked significantly fewer minutes overall (13.42% fewer minutes).

Increasing age was associated with incremental decreases in walking outcomes. Compared with the people aged 19-29, significantly decreased odds of having completed a walk ranged from 72% (70+ years) to 37% (50-59 years) for likelihood of having completed a walk, from 65% (70+ years) to 36% (30-39 years) for having completed multiple walks and 84% (70+ years) to 29% (40-49 years) for likelihood of having achieved 30 minutes walking. There were no significant differences between the age groups in total minutes spent walking briskly.

Socioeconomic status

There was evidence of a social gradient in walking outcomes whereby people with lower SES did less walking. Associations were particularly strong for educational attainment. Likelihood of having completed a walk, multiple walks or having achieved 30 minutes walking showed incremental decreases as educational attainment decreased. The lowest odds were for people without any qualifications where there were decreased odds of 78% for any walking, 55% for multiple walks and 74% for having achieved 30 minutes walking compared with people who had a degree or higher. Those who were unemployed were less likely to have completed a walk or achieved 30 minutes walking compared with people in employment/education, with decreased odds of 73% and 66% respectively. People with an economic status of 'other' (neither in employment/education nor unemployed, for example those who are considered 'homemakers) were the least likely to have done multiple walks, with a decrease in odds of 38% compared with people in education or employment. However, people in this group were predicted to spend 29.20% longer walking compared with people in education/employment. There were incremental decreases in likelihood of having completed a walk by employment category ranging from 35% for people in intermediate occupations, 50% for people in routine manual occupations and 66% in 'other' occupations compared with managerial occupations. There were decreases of 29%, 41% and 57% for likelihood of achieving 30 minutes walking for the same categories.

Household characteristics

Household characteristics were associated with different walking outcomes. Those who classified themselves as single had 34% and 28% increased odds of having completed multiple walks and having achieved 30 minutes walking respectively compared with people who were married or living as married. People who were widowed had decreased odds of having completed a walk (63%), multiple walks (45%) and achieving 30 minutes walking (71%).

Having children living in the household was positively associated with having completed any walks (17% higher odds) and achieving PA through walking (39% higher odds). There were mixed results for having access to a car; trends for multiple walks and total minutes walking were in the expected direction, with significantly increased odds of multiple walking (21%) for people who did not have access to a car compared with those who did, and a significant predicted increase in total brisk minutes walked of 31.59%. However, there were significantly decreased odds for achieving 30 minutes walking (29%).

Area deprivation

Associations between walking and area deprivation showed mixed results. Likelihood of having completed a walk decreased as area deprivation increased, with decreased odds of 38%, 47% and 52% in area deprivation quartiles 2, 3 and 4 respectively. There were also significantly decreased odds of achieving 30 minutes walking in quartiles 3 (30% decreased odds) and 4 (41% decreased odds). However, there were significant predicted increases of 28.22% and 28.27% of total minutes walking in deprivation quartiles 3 and 4 respectively.

Table 37 Likelihood (odds rations, 95% CIs) of people doing any walks, multiple walks and having achieved 30 minutes walking by demographic and socio-economic categories (n=4,456)

Walking outcome/	Any walks				Multiple walks				Recommended PA			
Respondent group	OR	95% CI		p	OR	95% CI		p	OR	95% CI		p
Female (base)	1				1				1			
Male	1.07	0.92	1.24	0.37	1	0.9	1.2	0.97	**1.58**	**1.37**	**1.81**	**<0.001**
Age group												
19-29 (base)	1				1							
30-39	1	0.68	1.47	0.99	**0.6**	**0.5**	**0.9**	**0**	0.94	0.74	1.19	0.6
40-49	0.74	0.52	1.05	0.09	**0.6**	**0.5**	**0.8**	**0**	**0.71**	**0.57**	**0.89**	**<0.001**
50-59	**0.63**	**0.45**	**0.88**	**0.01**	**0.5**	**0.4**	**0.7**	**<0.001**	**0.56**	**0.44**	**0.71**	**<0.001**
60-69	**0.38**	**0.28**	**0.53**	**<0.001**	**0.4**	**0.3**	**0.6**	**<0.001**	**0.29**	**0.22**	**0.37**	**<0.001**
70+	**0.28**	**0.2**	**0.38**	**<0.001**	**0.4**	**0.3**	**0.5**	**<0.001**	**0.16**	**0.12**	**0.21**	**<0.001**
Economic status												
In emp/edu (base)	1				1				1			
Unemployed	**0.27**	**0.21**	**0.34**	**<0.001**	**0.7**	**0.6**	**1**	**0.03**	**0.34**	**0.26**	**0.45**	**<0.001**
Other	**0.39**	**0.33**	**0.46**	**<0.001**	**0.6**	**0.5**	**0.7**	**<0.001**	**0.27**	**0.23**	**0.32**	**<0.001**
Employment category												
Managerial (base)	1				1				1			
Intermediate	**0.65**	**0.51**	**0.83**	**<0.001**	0.9	0.7	1.1	0.29	**0.71**	**0.58**	**0.87**	**<0.001**
Routine/man	**0.5**	**0.41**	**0.6**	**<0.001**	0.9	0.7	1	0.09	**0.59**	**0.5**	**0.69**	**<0.001**
Other	**0.34**	**0.24**	**0.48**	**<0.001**	1.2	0.8	1.9	0.38	**0.43**	**0.27**	**0.67**	**<0.001**
Qualifications												
Degree or above (base)	1				1				1			
Post- school	**0.66**	**0.51**	**0.85**	**0**	0.9	0.7	1.1	0.25	0.83	0.68	1	0.05
School	**0.43**	**0.34**	**0.55**	**<0.001**	**0.6**	**0.5**	**0.8**	**<0.001**	**0.46**	**0.38**	**0.55**	**<0.001**
None	**0.22**	**0.18**	**0.28**	**<0.001**	**0.5**	**0.4**	**0.6**	**<0.001**	**0.26**	**0.21**	**0.32**	**<0.001**
Marital status												
Married (base)	1				1				1			
Not married	0.97	0.82	1.15	0.7	**1.3**	**1.1**	**1.6**	**0**	**1.28**	**1.09**	**1.49**	**<0.001**
Widowed	**0.37**	**0.29**	**0.46**	**<0.001**	**0.7**	**0.5**	**0.9**	**0**	**0.29**	**0.21**	**0.4**	**<0.001**
Children in household												
No (base)	1				1				1			
Yes	**1.17**	**0.95**	**1.45**	**0.14**	1.1	0.9	1.3	0.44	**1.39**	**1.18**	**1.64**	**<0.001**
Car/van available												
Yes (base)	1				1				1			
No	0.86	0.73	1	0.05	**1.2**	**1**	**1.4**	**0.02**	**0.71**	**0.61**	**0.83**	**<0.001**
Area deprivation												
Quartile one (least) (base)	1				1				1			
Quartile two	**0.62**	**0.49**	**0.78**	**<0.001**	0.9	0.7	1.1	0.39	0.83	0.68	1	0.05
Quartile three	**0.53**	**0.42**	**0.67**	**<0.001**	1	0.8	1.2	0.85	**0.7**	**0.57**	**0.85**	**<0.001**
Quartile four (most)	**0.48**	**0.38**	**0.6**	**<0.001**	0.9	0.7	1.1	0.2	**0.59**	**0.48**	**0.71**	**<0.001**

(Significant results highlighted in bold)

Table 38 Predicted change total weekly walking time for brisk walks of at least ten minutes by demographic and socio-economic categories (n=1,460)

	Coeff.	P>t	95% CI		% predicted change
Female (base)	0.00				
Male	**-0.14**	**0.03**	**-0.27**	**-0.02**	**-13.42**
Age group					
19-29 (base)	0.00				
30-39	0.02	0.85	-0.18	0.21	1.91
40-49	0.08	0.39	-0.11	0.28	8.74
50-59	0.04	0.74	-0.18	0.25	3.74
60-69	0.13	0.31	-0.12	0.37	13.46
70+	0.03	0.86	-0.28	0.33	2.69
Economic status					
In emp/edu (base)	0.00				
Unemployed	0.16	0.26	-0.12	0.44	17.58
Other	**0.26**	**<0.01**	**0.10**	**0.42**	**29.20**
Employment category					
Managerial (base)	0.00				
Intermediate	-0.05	0.57	-0.23	0.13	-5.11
Routine/man	**0.16**	**0.04**	**0.01**	**0.31**	**17.01**
Other	0.28	0.12	-0.07	0.62	31.76
Qualifications					
Degree or above (base)	0.00				
Post- school	-0.07	0.38	-0.23	0.09	-6.95
School	0.06	0.53	-0.12	0.24	6.01
None	0.14	0.23	-0.09	0.36	14.60
Marital status					
Married (base)	0.00				
Not married	0.06	0.38	-0.08	0.20	6.46
Widowed	0.21	0.18	-0.10	0.51	23.11
Children in household					
No (base)	0.00				
Yes	-0.06	0.42	-0.21	0.09	-5.96
Car/van available					
Yes (base)	0.00				
No	**0.27**	**<0.01**	**0.14**	**0.41**	**31.59**
Area deprivation					
Quartile one (least) (base)	0.00				
Quartile two	0.06	0.49	-0.11	0.23	6.33
Quartile three	**0.25**	**0.01**	**0.07**	**0.43**	**28.22**
Quartile four (most)	**0.25**	**0.01**	**0.06**	**0.44**	**28.27**

(Significant results highlighted in bold)

Summary

Demographic, socioeconomic, household characteristics and area deprivation factors all had associations with walking outcomes in the univariate analyses. Since all measures were associated with walking all were included as covariates in the subsequent analysis between AWP and walking.

6.5 Relationships between Area Walking Potential and walking

This section examines relationships between AWP and walking. Regression analysis was used to examine relationships between AWP measures (destination accessibility, residential density, intersection density and walkability) with the four walking outcomes (any walking, multiple walks, having achieved 30 minutes walking and total minutes spent walking). Logistic regression was used to compare likelihood of achieving each walking outcome for people living in quartile 1 (the base category) with other quartiles for the binary walking outcomes. For total weekly minutes brisk walking linear regression was used to estimate differences in total walking minutes in quartiles 2-4 compared with quartile 1.

Initially, correlations between predictor variables were considered and Chi Square tests were used to test for the strength of associations between AWP and walking. The regression analysis then used a two-stage approach. In the first stage, bivariate associations between AWP and walking outcomes were examined. These analyses were carried out using both size zones (500m and 1000m) to test for sensitivity of associations to neighbourhood size zone. The second stage examines these associations while adjusting for covariates to consider whether associations observed in stage one remained after controlling for covariates.

6.5.1 Associations between predictor variables

Correlations between predictor variables are shown in Tables 39a and b. There were moderate to high correlations between AWP measures and all were statistically significant. As would be expected the highest were between walkability with its three composite measures where all correlation coefficients ranged from 0.57 to 0.75. There were moderate associations between residential density and intersection density (0.40 in 1000m zones, 0.43 in 500m zones) and weaker associations between destination accessibility and residential density (0.35 in 500m zones and 0.39 1000m zones). AWP measures were modelled separately with the walking outcomes due to the correlations between these measures to avoid confounding.

There was a strong correlation between economic status and age (correlation coefficient – 0.61, $p<0.01$); this is likely to be because the largest economic status category is 'doing something else' which includes being in retirement. The remaining correlations were weak (<0.39).

Table 39a Correlations between predictor variables in 1000m zones

	Dest. access	Res. den.	Int. den	Walka.	Sex	Age grp	Mar. stat.	Child	Econ stat.	Emp type	Edu	Car
Res. den.	**0.35** **<0.01**											
Int. den	**0.23** **<0.01**	**0.40** **<0.01**										
Walka.	**0.75** **<0.01**	**0.57** **<0.01**	**0.65** **<0.01**									
Sex	0.03 0.07	0.03 0.07	0.03 0.06	**0.04** **0.02**								
Age grp	**-0.06** **<0.01**	**-0.14** **<0.01**	**-0.07** **<0.01**	**-0.09** **<0.01**	**-0.05** **0.00**							
Mar. stat.	**0.13** **<0.01**	**0.10** **<0.01**	**0.04** **0.02**	**0.10** **<0.01**	**-0.10** **<0.01**	**0.06** **<0.01**						
Child	**-0.10** **<0.01**	**-0.03** **0.02**	**-0.04** **0.01**	**-0.09** **<0.01**	**-0.08** **<0.01**	**-0.27** **<0.01**	**-0.17** **<0.01**					
Econ stat.	-0.01 0.475	**-0.04** **0.00**	**-0.05** **0.00**	-0.03 0.05	**-0.14** **<0.01**	**-0.61** **<0.01**	**0.17** **<0.01**	**-0.17** **<0.01**				
Emp type	0.02 0.11	**0.10** **<0.01**	-0.03 0.09	**0.03** **0.05**	-0.02 0.14	-0.03 0.05	**0.18** **<0.01**	-0.01 0.46	**0.16** **<0.01**			
Edu	**-0.07** **<0.01**	-0.02 0.24	**-0.10** **<0.01**	**-0.08** **<0.01**	**-0.04** **0.01**	**0.33** **<0.01**	**0.12** **<0.01**	**-0.06** **<0.01**	**0.32** **<0.01**	**<0.01**		
Car	**0.18** **<0.01**	**0.22** **<0.01**	**0.10** **<0.01**	**0.19** **<0.01**	**-0.08** **<0.01**	**0.05** **<0.01**	**0.37** **<0.01**	**-0.11** **<0.01**	**0.22** **<0.01**	**0.29** **<0.01**	**0.22** **<0.01**	
Area dep.	**0.13** **<0.01**	**0.25** **<0.01**	0.02 0.19	**0.15** **<0.01**	-0.02 0.11	**-0.07** **<0.01**	**0.13** **<0.01**	0.02 0.30	**0.06** **<0.01**	**0.32** **<0.01**	**0.32** **<0.01**	**0.30** **<0.01**

(Significance values are shown beneath correlation coefficients. Significant results are highlighted in bold.)

Table 39b Correlations between predictor variables in 500m zones

	Res. den.	Int. den	Walka.	Sex	Age grp	Mar. stat.	Child	Econ stat.	Emp type	Edu	Car	Area dep.
Dest. access	**0.39**	**0.14**	**0.70**	0.03	**-0.10**	**0.11**	**-0.10**	-0.03	**0.03**	**-0.07**	**0.15**	**0.15**
	<0.01	**<0.01**	**<0.01**	0.06	**<0.01**	**<0.01**	**<0.01**	0.06	**0.03**	**<0.01**	**<0.01**	**<0.01**
Res. den.		**0.43**	**0.64**	**0.04**	**-0.12**	**0.11**	**-0.06**	-0.02	**0.09**	-0.02	**0.23**	**0.25**
		<0.01	**<0.01**	**0.01**	**<0.01**	**<0.01**	**<0.01**	0.11	**<0.01**	0.11	**<0.01**	**<0.01**
Int. den			**0.65**	0.03	**-0.07**	**0.04**	**-0.03**	**-0.04**	0.02	**<0.01**	**0.09**	**0.04**
			<0.01	0.07	**<0.01**	**0.01**	**0.02**	**0.00**	0.18	**<0.01**	**<0.01**	**0.01**
Walka.				**0.04**	**-0.12**	**0.10**	**-0.09**	**-0.04**	**0.06**	**-0.06**	**0.16**	**0.16**
				0.01	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**

(Significance values are shown beneath correlation coefficients. Significant results are highlighted in bold)

6.5.2 Associations between AWP and walking

Chi square tests were carried out to test the strength of associations between proportions of people achieving a positive walking outcome between AWP measure quartiles. Table 40 shows all relationships were significant at the $p<0.05$ level apart from intersection density and any walking in 500m zones and walkability and having achieved 30 minutes walking in 500m zones.

Table 40 p values for Chi square tests for strength of associations between AWP with walking outcomes

	Destination accessibility	Residential density	Intersection density	Walkability
1000m zones				
Any walking	**<0.01**	**0.009**	**0.014**	**0.002**
Multiple walks	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Achieved 30 minutes walking	**0.006**	**0.037**	**<0.01**	**<0.01**
500m zones				
Any walking	**0.033**	**0.026**	0.619	**0.017**
Multiple walks	**<0.01**	**0.003**	**<0.01**	**<0.01**
Achieved 30 minutes walking	**0.045**	**0.018**	**0.022**	0.056

Tables 41 to 52 show the relationships between AWP and walking. Bivariate models are presented first followed by fully adjusted regression models for each AWP measure. Bivariate analysis was carried out using two neighbourhood geographies (500m and 1000m zones). Associations were stronger using 1000m zones so in the adjusted analysis 1000m zones were used.

6.5.2.1 Destination accessibility

Tables 41 and 42 show outcomes of the bivariate regression between destination accessibility with the four walking outcomes measured using two size zones. There were 50% increased odds of having completed a walk for people living in destination accessibility quartile 4 compared with quartile 1 in 1000m zones and 32% increased odds in 500m zones. There was a dose-response relationship for likelihood of completing multiple walks in 1000m zones, with increased odds of 21% in quartile 2, 36% in quartile 3 and 82% quartile 4. In 500m zones there were increased odds of 35% in quartile 3 and 54% in quartile 4. There were weaker associations with likelihood of having achieved 30 minutes walking with a significant increase of 24% in quartile 4 measured using 1000m zones and no significant associations in 500m zones. There were decreases in quartile 2 for likelihood of having done any walks (20% decrease) and quartile 3 for predicted total minutes spent walking (23.80% fewer minutes per week).

After adjustment for covariates, similar associations remained with likelihood of completing a walk and multiple walks although results were slightly attenuated (Table 43). People living in quartile 4 had 46% increased odds of having completed a walk compared with people in quartile 1. The dose-response increases in all quartiles for likelihood of having completed multiple walks was still evident with increased odds ranging from 39% (quartile 2) to 69% (quartile 4). There were no longer significant associations between destination accessibility and likelihood of having achieved 30 minutes walking or total minutes walking.

Table 41 Bivariate logistic regression models showing associations between destination accessibility quartiles measured using 1000m and 500m size zones with binary walking outcomes

Walking outcome/Destination accessibility quartiles	1000m zones				500m zones			
	OR	p	95% CI		OR	p	95% CI	
Any walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	**0.80**	**0.05**	**0.65**	**1.00**	0.86	0.17	0.69	1.07
Quartile 3	0.88	0.25	0.71	1.10	1.09	0.46	0.87	1.36
Quartile 4	**1.50**	**<0.01**	**1.16**	**1.94**	**1.32**	**0.02**	**1.04**	**1.68**
Multiple walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	**1.21**	**0.03**	**1.01**	**1.45**	0.89	0.18	0.74	1.06
Quartile 3	**1.36**	**<0.01**	**1.14**	**1.63**	**1.35**	**0.00**	**1.13**	**1.62**
Quartile 4	**1.82**	**<0.01**	**1.51**	**2.20**	**1.54**	**0.00**	**1.28**	**1.85**
30 minutes walking								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.89	0.25	0.74	1.08	0.84	0.06	0.69	1.01
Quartile 3	0.91	0.34	0.75	1.10	1.14	0.19	0.94	1.38
Quartile 4	**1.24**	**0.03**	**1.02**	**1.51**	1.15	0.16	0.95	1.40

Table 42 Bivariate linear regression models showing associations between destination accessibility quartiles measured using 1000m and 500m size zones with total minutes walking

Destination accessibility quartiles	1000m zones					500m zones				
	Coeff.	p	95% CI		% change	Coeff.	p	95% CI		% change
Quartile 1 (base)	0.00					0.00				
Quartile 2	0.03	0.78	-0.17	0.22	2.78	-0.02	0.85	-0.21	0.17	-1.81
Quartile 3	**0.21**	**0.02**	**0.03**	**0.40**	**23.80**	0.16	0.10	-0.03	0.34	17.11
Quartile 4	0.18	0.05	0.00	0.36	19.51	0.14	0.13	-0.04	0.32	15.01

Table 43 Fully adjusted regression models showing associations between destination accessibility quartiles and covariate measures with walking outcomes using 1000m zones

	Any walks				Multiple walks				Recommended PA				Total walking				
	OR	p	95% CI		OR	p	95%CI		OR	p	95% CI		Coef	p	95% CI		% change
Destination accessibility																	
Quartile 1 (base)	1.00								1.00				0.00				
Quartile 2	0.96	0.73	0.76	1.21	**1.39**	**<0.01**	**1.14**	**1.68**	1.04	0.68	0.85	1.29	-0.03	0.79	-0.23	0.17	-2.70
Quartile 3	1.04	0.76	0.82	1.32	**1.54**	**<0.01**	**1.27**	**1.86**	1.07	0.56	0.86	1.32	0.18	0.06	-0.01	0.37	19.94
Quartile 4	**1.46**	**0.01**	**1.11**	**1.92**	**1.69**	**<0.01**	**1.37**	**2.07**	1.17	0.17	0.94	1.45	0.13	0.20	-0.07	0.32	13.50
Sex																	
Female (base)	1.00								1.00				0.00				
Male	1.04	0.69	0.86	1.25	0.99	0.90	0.86	1.14	**1.53**	**<0.01**	**1.31**	**1.78**	-0.12	0.07	-0.25	0.01	-11.30
Age group																	
19-29 (base)	1.00								1.00								
30-39	1.01	0.96	0.68	1.49	**0.77**	**0.045**	**0.59**	**0.99**	0.96	0.76	0.75	1.24	0.08	0.42	-0.12	0.29	8.75
40-49	0.88	0.49	0.62	1.26	0.82	0.10	0.64	1.04	0.81	0.09	0.63	1.03	0.20	0.06	0.00	0.40	22.06
50-59	0.72	0.07	0.50	1.02	**0.68**	**<0.01**	**0.53**	**0.88**	**0.69**	**<0.01**	**0.53**	**0.89**	0.13	0.29	-0.11	0.36	13.37
60-69	**0.38**	**<0.01**	**0.26**	**0.56**	**0.47**	**<0.01**	**0.35**	**0.63**	**0.42**	**<0.01**	**0.31**	**0.57**	0.04	0.79	-0.25	0.33	4.12
70+	**0.27**	**<0.01**	**0.17**	**0.41**	**0.34**	**<0.01**	**0.24**	**0.47**	**0.25**	**<0.01**	**0.17**	**0.37**	-0.20	0.30	-0.57	0.18	-17.94
Economic status																	
In emp/edu (base)	1.00								1.00								
Unemployed	**0.36**	**<0.01**	**0.28**	**0.47**	**0.55**	**<0.01**	**0.43**	**0.70**	**0.44**	**<0.01**	**0.33**	**0.59**	0.03	0.82	-0.25	0.32	3.47
Other	1.01	0.95	0.76	1.34	0.96	0.74	0.77	1.20	**0.72**	**0.01**	**0.56**	**0.92**	**0.31**	**0.01**	**0.09**	**0.52**	**35.81**
Employment category																	
Managerial (base)	1.00								1.00								
Intermediate	0.89	0.44	0.66	1.19	1.01	0.90	0.82	1.26	0.94	0.57	0.75	1.18	-0.06	0.52	-0.26	0.13	-6.26
Routine/man	0.92	0.55	0.70	1.21	1.04	0.70	0.85	1.27	0.88	0.24	0.72	1.09	0.12	0.19	-0.06	0.30	12.96
Other	**0.44**	**<0.01**	**0.26**	**0.75**	0.76	0.22	0.50	1.18	**0.55**	**0.02**	**0.32**	**0.92**	0.22	0.26	-0.16	0.60	24.54
Qualifications																	
Degree or above (bas	1.00				1.00				1.00								
Post- school	0.72	0.05	0.51	1.00	**0.79**	**0.03**	**0.64**	**0.98**	0.87	0.19	0.70	1.08	-0.12	0.17	-0.29	0.05	-11.48
School	**0.65**	**0.01**	**0.47**	**0.89**	**0.63**	**<0.01**	**0.50**	**0.78**	**0.64**	**<0.01**	**0.50**	**0.80**	-0.08	0.42	-0.29	0.12	-7.98
None	**0.42**	**<0.01**	**0.31**	**0.59**	**0.43**	**<0.01**	**0.34**	**0.55**	**0.54**	**<0.01**	**0.41**	**0.71**	-0.07	0.62	-0.34	0.20	-6.69
Marital status																	
Married (base)	1.00				1.00				1.00								
Not married	**0.77**	**0.03**	**0.62**	**0.97**	0.94	0.51	0.80	1.12	1.18	0.06	0.99	1.41	0.00	0.99	-0.15	0.15	-0.15
Widowed	**0.55**	**<0.01**	**0.41**	**0.73**	**0.67**	**0.01**	**0.51**	**0.89**	0.95	0.80	0.67	1.37	0.05	0.78	-0.28	0.38	4.76
Children in household																	
No (base)	1.00				1.00				1.00								
Yes	**0.68**	**0.01**	**0.52**	**0.89**	0.86	0.11	0.71	1.04	1.03	0.78	0.84	1.25	-0.07	0.40	-0.24	0.10	-7.00
Car/van available																	
Yes (base)	1.00				1.00				1.00				**0.00**				
No	**1.89**	**<0.01**	**1.54**	**2.32**	**1.66**	**<0.01**	**1.39**	**1.98**	1.10	0.32	0.91	1.34	**0.18**	**0.03**	**0.02**	**0.35**	**20.14**
Area deprivation																	
Quartile one (base)	1.00				1.00				1.00				0.00				
Quartile two	**0.65**	**<0.01**	**0.49**	**0.86**	**0.75**	**0.01**	**0.61**	**0.92**	0.82	0.06	0.67	1.01	0.01	0.91	-0.17	0.19	1.12
Quartile three	**0.59**	**<0.01**	**0.44**	**0.79**	**0.77**	**0.02**	**0.62**	**0.96**	**0.79**	**0.04**	**0.63**	**0.99**	0.19	0.06	-0.01	0.39	21.12
Quartile four	**0.62**	**<0.01**	**0.46**	**0.83**	**0.70**	**<0.01**	**0.57**	**0.88**	**0.69**	**<0.01**	**0.54**	**0.87**	0.13	0.24	-0.09	0.35	13.91

6.5.2.2 Residential density

Associations were weaker between residential density and walking outcome than for the other measures. However, there were some increases in walking outcomes with increasing residential density in the bivariate analyses (Tables 44 and 45). There were significant increases in likelihood of having completed multiple walks for people living in residential density quartile 4 (increased odds of 38% and 41% in 1000m and 500m zones respectively) and having achieved 30 minutes walking (32% increased odds in 1000m zones and 34% in 500m zones) compared with residential density quartile 1. There was a significant decrease in likelihood of having completed a walk in residential quartile 3 compared with quartile 1, with reduced odds of 23%. No significant associations were observed between residential density and total minutes walking. No significant associations between residential density and walking remained after controlling for covariates (Table 46). This suggests that the associations observed in the bivariate analysis were likely to be the result of confounding by other factors rather than the direct influence of residential density.

Table 44 Bivariate regression models showing associations between residential density quartiles measured using 1000m and 500m size zones with binary walking outcomes

Residential	1000m zones				500m zones			
density quartiles	OR	p	95% CI		OR	p	95% CI	
Any walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.97	0.77	0.77	1.21	**0.74**	**0.01**	**0.59**	**0.92**
Quartile 3	**0.77**	**0.02**	**0.61**	**0.96**	0.89	0.33	0.71	1.12
Quartile 4	1.23	0.10	0.96	1.56	1.13	0.31	0.89	1.45
Multiple walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	1.06	0.50	0.89	1.27	0.91	0.31	0.76	1.09
Quartile 3	1.01	0.89	0.84	1.22	1.07	0.46	0.89	1.29
Quartile 4	**1.38**	**<0.01**	**1.15**	**1.66**	**1.41**	**<0.01**	**1.17**	**1.71**
30 minutes walking								
Quartile 1 (base)	1.00				1.00			
Quartile 2	1.01	0.93	0.83	1.22	1.01	0.90	0.84	1.22
Quartile 3	0.98	0.85	0.80	1.20	0.93	0.49	0.76	1.14
Quartile 4	**1.32**	**<0.01**	**1.09**	**1.61**	**1.34**	**<0.01**	**1.10**	**1.63**

Table 45 Bivariate regression models showing associations between residential density quartiles measured using 1000m and 500m size zones with total minutes walking

Residential density quartiles	Coeff.	p	95% CI		% change	Coeff.	p	95% CI		% change
Quartile 1 (base)	1.00					1.00				
Quartile 2	0.09	0.38	-0.11	0.28	9.14	-0.11	0.24	-0.30	0.08	-10.71
Quartile 3	0.00	0.99	-0.20	0.19	-0.16	-0.05	0.65	-0.25	0.15	-4.57
Quartile 4	0.13	0.15	-0.05	0.30	13.79	0.11	0.23	-0.07	0.29	11.64

Table 46 Fully adjusted regression models showing associations between residential density quartiles and covariate measures with walking outcomes using 1000m zones

	Any walks				Multiple walks				Recommended PA				Total walking				
	OR	p	95% CI		OR	p	95%CI		OR	p	95% CI		Coef	p	95% CI		% change
Residential density																	
Quartile 1 (base)	1.00				1.00				1.00				0.00				
Quartile 2	1.00	0.99	0.78	1.27	1.07	0.51	0.88	1.29	0.99	0.94	0.80	1.22	0.09	0.39	-0.11	0.28	8.97
Quartile 3	0.87	0.26	0.67	1.11	1.09	0.39	0.89	1.33	1.14	0.25	0.91	1.42	-0.08	0.44	-0.28	0.12	-7.49
Quartile 4	1.09	0.55	0.83	1.43	1.15	0.19	0.94	1.40	1.19	0.12	0.96	1.48	0.06	0.52	-0.12	0.24	6.29
Sex																	
Female (base)	1.00				1.00				1.00				0.00				
Male	1.04	0.65	0.87	1.26	1.00	0.97	0.87	1.15	**1.52**	**<0.01**	**1.31**	**1.78**	-0.12	0.07	-0.25	0.01	-11.49
Age group																	
19-29 (base)	1.00				1.00				1.00				0.00				
30-39	1.01	0.94	0.69	1.49	0.76	0.04	0.59	0.99	0.96	0.74	0.75	1.23	0.08	0.43	-0.12	0.29	8.72
40-49	0.89	0.51	0.62	1.26	0.81	0.09	0.63	1.04	0.82	0.10	0.64	1.04	0.20	0.06	-0.01	0.40	21.71
50-59	0.71	0.07	0.50	1.02	**0.67**	**<0.01**	**0.52**	**0.86**	**0.69**	**0.01**	**0.53**	**0.89**	0.11	0.34	-0.12	0.35	12.07
60-69	**0.38**	**<0.01**	**0.26**	**0.57**	**0.48**	**<0.01**	**0.36**	**0.64**	**0.42**	**0.00**	**0.31**	**0.58**	0.03	0.82	-0.26	0.32	3.50
70+	**0.27**	**<0.01**	**0.18**	**0.42**	**0.35**	**<0.01**	**0.25**	**0.48**	**0.26**	**0.00**	**0.17**	**0.38**	-0.20	0.30	-0.57	0.18	-17.99
Economic status																	
In emp/edu (base)	1.00				1.00				1.00				0.00				
Unemployed	**0.35**	**<0.01**	**0.27**	**0.46**	**0.54**	**<0.01**	**0.43**	**0.70**	**0.44**	**0.00**	**0.33**	**0.59**	0.04	0.80	-0.25	0.32	3.82
Other	0.99	0.97	0.75	1.32	0.96	0.69	0.77	1.19	**0.71**	**0.01**	**0.56**	**0.91**	**0.30**	**0.01**	**0.09**	**0.52**	**35.44**
Employment category																	
Managerial (base)	1.00				1.00				1.00				0.00				
Intermediate	0.90	0.46	0.67	1.20	1.01	0.91	0.82	1.25	0.94	0.58	0.75	1.18	-0.05	0.59	-0.25	0.14	-5.31
Routine/man	0.91	0.51	0.69	1.20	1.03	0.78	0.84	1.26	0.88	0.23	0.71	1.08	0.13	0.17	-0.06	0.31	13.54
Other	**0.44**	**<0.01**	**0.26**	**0.74**	0.79	0.28	0.52	1.21	**0.54**	**0.02**	**0.32**	**0.92**	0.23	0.22	-0.14	0.61	26.48
Qualifications																	
Degree or above (base	1.00				1.00				1.00				0.00				
Post- school	**0.70**	**0.03**	**0.50**	**0.97**	**0.76**	**0.01**	**0.61**	**0.94**	0.86	0.17	0.69	1.07	-0.13	0.13	-0.31	0.04	-12.46
School	**0.64**	**0.01**	**0.47**	**0.88**	**0.60**	**<0.01**	**0.48**	**0.75**	**0.63**	**0.00**	**0.50**	**0.79**	-0.09	0.38	-0.30	0.11	-8.76
None	**0.41**	**<0.01**	**0.30**	**0.57**	**0.42**	**<0.01**	**0.33**	**0.53**	**0.54**	**0.00**	**0.41**	**0.71**	-0.08	0.56	-0.35	0.19	-7.72
Marital status																	
Married (base)	1.00				1.00				1.00				0.00				
Not married	0.80	0.05	0.64	0.99	0.96	0.68	0.81	1.14	1.19	0.05	1.00	1.42	0.00	1.00	-0.15	0.15	0.05
Widowed	**0.55**	**<0.01**	**0.41**	**0.73**	**0.69**	**0.01**	**0.52**	**0.92**	0.96	0.82	0.67	1.38	0.05	0.78	-0.28	0.38	4.91
Children in household																	
No (base)	1.00				1.00				1.00				0.00				
Yes	**0.66**	**<0.01**	**0.50**	**0.86**	0.84	0.08	0.69	1.02	1.03	0.77	0.85	1.25	-0.10	0.26	-0.26	0.07	-9.14
Car/van available																	
Yes (base)	1.00				1.00				1.00				0.00				
No	**1.93**	**<0.01**	**1.57**	**2.37**	**1.71**	**<0.01**	**1.43**	**2.03**	1.09	0.38	0.90	1.32	**0.18**	**0.03**	**0.01**	**0.35**	**19.89**
Area deprivation																	
Quartile one (base)	1.00				1.00				1.00				0.00				
Quartile two	**0.67**	**0.01**	**0.51**	**0.89**	**0.79**	**0.02**	**0.65**	**0.97**	0.81	0.05	0.66	1.00	0.04	0.65	-0.14	0.22	4.24
Quartile three	**0.62**	**<0.01**	**0.46**	**0.83**	0.83	0.09	0.67	1.03	**0.78**	**0.03**	**0.62**	**0.98**	**0.22**	**0.03**	**0.03**	**0.42**	**24.80**
Quartile four	**0.65**	**<0.01**	**0.48**	**0.87**	**0.75**	**0.01**	**0.60**	**0.94**	**0.66**	**<0.01**	**0.52**	**0.84**	0.17	0.12	-0.04	0.38	18.21

6.5.2.3 Intersection density

There were some significant associations with intersection density and walking (Tables 47 and 48). There were 34% increased odds of having completed a walk for people living in neighbourhoods with highest intersection density (quartile 4) compared with the lowest (quartile 1) in 1000m zones. Again, there were stronger outcomes for multiple walks with 81% increased odds of having completed multiple walks for people living in quartile 4 using 1000m zones and 35% using 500m zones. Amongst residents in neighbourhoods with highest intersection density (quartile 4) there was a 56% increased odds of having achieved 30 minutes walking compared with those in quartile 1 (lowest intersection density) in 1000m zones and 34% increase using 500m zones.

After adjustment for covariates (Table 49) there were no longer any significant associations with likelihood of having completed a walk, suggesting the previously observed associations were a result of residual confounding driven by factors such as educational attainment, area deprivation, age group and employment status. There were still significant increases in likelihood of having completed multiple walks for people living in quartile 4 compared with quartile 1 (57% increased odds) but not in quartile 3 as in the unadjusted model. Significant associations remained for likelihood of having achieved 30 minutes walking for people living in quartile 4 although lower than in the unadjusted model with a 36% increase in odds. There were no significant associations with total minutes walking in either of the models.

Table 47 Bivariate regression models showing associations between intersection density quartiles measured using 1000m and 500m size zones with binary walking outcomes

Intersection density	1000m zones OR	p	95% CI		500m zones OR	p	95% CI	
Any walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.86	0.20	0.69	1.08	0.88	0.27	0.70	1.11
Quartile 3	0.99	0.95	0.79	1.24	0.94	0.59	0.74	1.18
Quartile 4	**1.34**	**0.01**	**1.06**	**1.70**	1.03	0.82	0.81	1.29
Multiple walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	1.04	0.69	0.86	1.25	0.96	0.67	0.80	1.15
Quartile 3	1.03	0.75	0.86	1.24	1.14	0.15	0.95	1.37
Quartile 4	**1.81**	**<0.01**	**1.51**	**2.18**	**1.35**	**<0.01**	**1.12**	**1.61**
30 minutes walking								
Quartile 1 (base)	1.00				1.00			
Quartile 2	1.11	0.32	0.91	1.35	1.04	0.67	0.85	1.28
Quartile 3	0.94	0.53	0.77	1.14	1.22	0.05	1.00	1.48
Quartile 4	**1.56**	**<0.01**	**1.29**	**1.89**	**1.34**	**<0.01**	**1.11**	**1.63**

Table 48 Bivariate regression models showing associations between intersection density quartiles measured using 1000m and 500m size zones with total minutes walking

Intersection density quartiles	Coeff.	p	95% CI		% change	Coeff.	p	95% CI		% change
Quartile 1 (base)	1.00					1.00				
Quartile 2	0.07	0.52	-0.14	0.27	6.90	0.08	0.43	-0.12	0.28	8.33
Quartile 3	-0.09	0.41	-0.30	0.12	-8.47	-0.01	0.91	-0.21	0.19	-1.16
Quartile 4	0.12	0.20	-0.06	0.31	12.88	0.12	0.18	-0.06	0.30	12.85

Table 49 Fully adjusted regression models showing associations between intersection density quartiles and covariate measures with walking outcomes using 1000m zones

	Any walks				Multiple walks				Recommended PA				Total walking				
	OR	p	95% CI		OR	p	95% CI		OR	p	95% CI		Coef.	p	95% CI		% change
Intersection density																	
Quartile 1 (base)	1.00				1.00				1.00				0.00				
Quartile 2	0.90	0.37	0.71	1.14	1.06	0.54	0.87	1.29	1.14	0.23	0.92	1.42	0.04	0.71	-0.16	0.24	3.82
Quartile 3	0.98	0.89	0.77	1.26	1.00	0.98	0.82	1.21	0.90	0.33	0.72	1.11	-0.16	0.15	-0.37	0.06	-14.37
Quartile 4	1.11	0.39	0.87	1.43	**1.57**	**<0.01**	**1.30**	**1.90**	**1.36**	**<0.01**	**1.11**	**1.67**	0.10	0.29	-0.08	0.28	10.52
Sex																	
Female (base)	1.00				1.00				1.00				0.00				
Male	1.05	0.62	0.87	1.26	0.99	0.90	0.86	1.14	**1.52**	**<0.01**	**1.31**	**1.77**	-0.12	0.07	-0.25	0.01	-11.22
Age group																	
19-29 (base)	1.00				1.00				1.00				0.00				
30-39	1.00	0.99	0.68	1.48	0.77	0.05	0.60	1.00	0.98	0.87	0.76	1.26	0.11	0.32	-0.10	0.31	11.19
40-49	0.88	0.47	0.62	1.25	0.81	0.10	0.63	1.04	0.81	0.10	0.64	1.04	**0.22**	**0.04**	**0.01**	**0.42**	24.15
50-59	0.70	0.05	0.49	1.00	**0.68**	**<0.01**	**0.53**	**0.87**	**0.70**	**0.01**	**0.54**	**0.90**	0.13	0.28	-0.11	0.36	13.85
60-69	**0.38**	**<0.01**	**0.25**	**0.56**	**0.48**	**<0.01**	**0.36**	**0.64**	**0.43**	**<0.01**	**0.31**	**0.58**	0.05	0.72	-0.24	0.34	5.36
70+	**0.27**	**<0.01**	**0.17**	**0.41**	**0.34**	**<0.01**	**0.25**	**0.48**	**0.25**	**<0.01**	**0.17**	**0.38**	-0.20	0.29	-0.57	0.17	-18.13
Economic status																	
In emp/edu (base)	1.00				1.00				1.00				0.00				
Unemployed	**0.36**	**<0.01**	**0.27**	**0.47**	**0.56**	**<0.01**	**0.44**	**0.72**	**0.45**	**<0.01**	**0.34**	**0.60**	0.03	0.85	-0.26	0.31	2.87
Other	0.99	0.97	0.75	1.32	0.95	0.67	0.77	1.19	**0.71**	**0.01**	**0.55**	**0.91**	**0.30**	**0.01**	**0.08**	**0.51**	34.76
Employment category																	
Managerial (base)	1.00				1.00				1.00				0.00				
Intermediate	0.90	0.46	0.67	1.20	1.00	0.97	0.80	1.23	0.92	0.50	0.74	1.16	-0.07	0.51	-0.26	0.13	-6.43
Routine/man	0.91	0.52	0.70	1.20	1.03	0.76	0.84	1.26	0.88	0.24	0.72	1.09	0.12	0.19	-0.06	0.30	12.87
Other	**0.44**	**<0.01**	**0.26**	**0.74**	0.78	0.25	0.51	1.19	**0.54**	**0.02**	**0.32**	**0.91**	0.21	0.28	-0.17	0.58	22.97
Qualifications																	
Degree or above (bas	1.00				1.00				1.00				0.00				
Post- school	**0.70**	**0.03**	**0.50**	**0.97**	**0.77**	**0.02**	**0.63**	**0.96**	0.87	0.19	0.70	1.07	-0.12	0.18	-0.29	0.05	-11.13
School	**0.63**	**<0.01**	**0.46**	**0.87**	**0.63**	**<0.01**	**0.50**	**0.78**	**0.64**	**<0.01**	**0.51**	**0.81**	-0.09	0.39	-0.29	0.12	-8.47
None	**0.41**	**<0.01**	**0.30**	**0.57**	**0.43**	**<0.01**	**0.34**	**0.55**	**0.54**	**<0.01**	**0.41**	**0.71**	-0.07	0.60	-0.34	0.20	-6.91
Marital status																	
Married (base)	1.00				1.00				1.00				0.00				
Not married	**0.79**	**0.04**	**0.63**	**0.99**	0.96	0.65	0.81	1.14	1.19	0.06	1.00	1.42	-0.01	0.90	-0.16	0.14	-0.93
Widowed	**0.56**	**<0.01**	**0.42**	**0.74**	**0.72**	**0.02**	**0.54**	**0.95**	0.98	0.93	0.69	1.41	0.05	0.75	-0.27	0.38	5.46
Children in household																	
No (base)	1.00				1.00				1.00				0.00				
Yes	**0.66**	**<0.01**	**0.51**	**0.87**	0.85	0.10	0.70	1.03	1.02	0.83	0.84	1.24	-0.10	0.22	-0.27	0.06	-9.91
Car/van available																	
Yes (base)	1.00				1.00				1.00				0.00				
No	**1.92**	**<0.01**	**1.57**	**2.36**	**1.65**	**<0.01**	**1.38**	**1.96**	1.08	0.45	0.89	1.31	**0.18**	**0.04**	**0.01**	**0.35**	**19.76**
Area deprivation																	
Quartile one (least) (	1.00				1.00				1.00				0.00				
Quartile two	**0.66**	**<0.01**	**0.50**	**0.88**	**0.78**	**0.02**	**0.64**	**0.95**	0.82	0.06	0.67	1.01	0.04	0.67	-0.14	0.22	4.00
Quartile three	**0.61**	**<0.01**	**0.45**	**0.81**	0.85	0.14	0.69	1.06	0.82	0.09	0.66	1.03	**0.23**	**0.02**	**0.04**	**0.42**	**26.01**
Quartile four	**0.65**	**<0.01**	**0.48**	**0.87**	**0.80**	**0.04**	**0.64**	**0.99**	**0.72**	**0.01**	**0.57**	**0.90**	0.19	0.08	-0.02	0.40	20.90

6.5.2.4 Walkability

More associations were found between walkability and walking outcomes than for the other measures in bivariate models (Tables 50 and 51). There were significant increases in walking outcomes for people living in quartile 4 for all walking outcomes. Associations were strongest for multiple walks where there were significant increases in quartiles 3 and 4 in both size zones (29% and 87% in 1000m zones and 26% and 69% in 500m zones). Increased odds of 42% and 40% were observed for likelihood of having achieved 30 minutes walking in quartile 4, 1000m and 500m zones respectively. There were predicted increases of 21.61% in minutes per week walking for people living in quartile 4 (1000m zones) and 20.87 in 500m zones. There were also significant increases for people living in quartile 4 1000m zones for having completed a walk (40% increased odds).

After adjusting for covariates (Table 52), Walkability no longer showed the most associations with walking outcomes. There were no longer significant associations with likelihood of having completed a walk or total minutes walking. Significant relationships remained in quartile 4 for likelihood of having completed multiple walks (67% increased odds) and a smaller increase for having achieved 30 minutes walking (32% increased odds).

Table 50 Bivariate regression models showing associations between walkability quartiles measured using 1000m and 500m size zones with binary walking outcomes

	1000m zones				500m zones			
Walkability	OR	p	95% CI		OR	p	95% CI	
Any walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.77	0.02	0.62	0.95	0.83	0.10	0.66	1.04
Quartile 3	0.98	0.83	0.78	1.22	1.05	0.69	0.84	1.31
Quartile 4	**1.40**	**0.01**	**1.10**	**1.79**	1.28	0.05	1.00	1.63
Multiple walks								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.93	0.44	0.78	1.12	0.98	0.83	0.82	1.18
Quartile 3	**1.29**	**0.01**	**1.08**	**1.55**	**1.26**	**0.01**	**1.05**	**1.51**
Quartile 4	**1.87**	**<0.01**	**1.55**	**2.26**	**1.69**	**<0.01**	**1.40**	**2.05**
30 minutes walking								
Quartile 1 (base)	1.00				1.00			
Quartile 2	0.93	0.48	0.77	1.13	1.05	0.65	0.86	1.27
Quartile 3	0.92	0.37	0.75	1.11	1.09	0.37	0.90	1.32
Quartile 4	**1.42**	**<0.01**	**1.17**	**1.73**	**1.40**	**<0.01**	**1.15**	**1.72**

Table 51 Bivariate regression models showing associations between walkability quartiles measured using 1000m and 500m size zones with total minutes walking

Walkability quartiles	Coeff.	p	95% CI		% change	Coeff.	p	95% CI		% change
Quartile 1 (base)	1.00					1.00				
Quartile 2	0.03	0.80	-0.18	0.23	2.60	0.01	0.92	-0.19	0.21	1.00
Quartile 3	0.09	0.38	-0.11	0.28	9.14	0.10	0.32	-0.09	0.29	10.22
Quartile 4	**0.20**	**0.04**	**0.01**	**0.38**	**21.61**	**0.19**	**0.049**	**0.00**	**0.38**	**20.87**

Table 52 Fully adjusted logistic regression models showing associations between walkability quartiles and covariate measures with walking outcomes using 1000m zones

	Any walks				Multiple walks				Recommended PA				Total walking				
	OR	p	95% CI		OR	p	95% CI		OR	p	95% CI		Coeff	p	95% CI		% change
Walkability																	
Quartile 1 (base)	1.00				1.00				1.00				1.00				
Quartile 2	0.92	0.46	0.72	1.16	1.04	0.69	0.86	1.26	1.06	0.59	0.86	1.31	-0.02	0.89	-0.22	0.19	-1.50
Quartile 3	1.12	0.37	0.87	1.43	1.42	0.00	1.17	1.72	1.02	0.86	0.82	1.26	0.05	0.62	-0.15	0.25	5.21
Quartile 4 (highest)	1.29	0.06	0.99	1.67	**1.67**	**0.00**	**1.36**	**2.05**	**1.32**	**0.01**	**1.06**	**1.64**	0.14	0.16	-0.06	0.34	15.55
Sex																	
Female (base)	1.00				1.00				1.00				1.00				
Male	1.04	0.67	0.86	1.25	0.99	0.84	0.85	1.14	**1.52**	**0.00**	**1.30**	**1.77**	-0.13	0.06	-0.26	0.00	-11.94
Age group																	
19-29 (base)	1.00				1.00				1.00				0.00				
30-39	1.01	0.97	0.68	1.49	0.77	0.05	0.59	1.00	0.97	0.81	0.75	1.25	0.09	0.42	-0.12	0.29	8.99
40-49	0.88	0.49	0.62	1.26	0.82	0.11	0.64	1.05	0.81	0.10	0.64	1.04	0.20	0.06	-0.01	0.40	21.86
50-59	0.71	0.06	0.49	1.01	**0.68**	**<0.01**	**0.53**	**0.88**	**0.69**	**0.01**	**0.54**	**0.89**	0.12	0.33	-0.12	0.35	12.40
60-69	**0.38**	**0.00**	**0.26**	**0.57**	**0.48**	**<0.01**	**0.36**	**0.65**	**0.43**	**0.00**	**0.31**	**0.58**	0.04	0.79	-0.25	0.33	4.05
70+	**0.27**	**0.00**	**0.17**	**0.42**	**0.34**	**<0.01**	**0.25**	**0.48**	**0.25**	**0.00**	**0.17**	**0.38**	-0.19	0.33	-0.56	0.19	-17.14
Economic status																	
In emp/edu (base)	1.00				1.00				1.00				0.00				
Unemployed	**0.36**	**0.00**	**0.28**	**0.47**	**0.56**	**<0.01**	**0.43**	**0.71**	**0.45**	**<0.01**	**0.34**	**0.60**	0.05	0.73	-0.24	0.34	5.14
Other	1.00	1.00	0.75	1.32	0.96	0.72	0.77	1.20	**0.72**	**0.01**	**0.56**	**0.92**	**0.30**	**0.01**	**0.08**	**0.51**	**34.63**
Employment category																	
Managerial (base)	1.00				1.00				1.00				0.00				
Intermediate	0.89	0.46	0.67	1.20	1.00	0.99	0.81	1.24	0.93	0.55	0.74	1.17	-0.07	0.51	-0.26	0.13	-6.39
Routine/man	0.92	0.53	0.70	1.20	1.03	0.76	0.84	1.26	0.88	0.22	0.71	1.08	0.12	0.19	-0.06	0.31	13.09
Other	**0.44**	**<0.01**	**0.26**	**0.74**	0.79	0.28	0.52	1.21	**0.54**	**0.02**	**0.32**	**0.92**	0.22	0.25	-0.16	0.59	24.50
Qualifications																	
Degree or above (bas	1.00				1.00				1.00				0.00				
Post- school	0.71	0.05	0.51	0.99	**0.80**	**0.04**	**0.65**	**0.99**	0.88	0.24	0.71	1.09	-0.11	0.21	-0.28	0.06	-10.54
School	**0.65**	**0.01**	**0.47**	**0.89**	**0.65**	**<0.01**	**0.52**	**0.81**	**0.65**	**<0.01**	**0.52**	**0.82**	-0.07	0.53	-0.27	0.14	-6.41
None	**0.42**	**<0.01**	**0.31**	**0.59**	**0.45**	**<0.01**	**0.35**	**0.57**	**0.56**	**<0.01**	**0.42**	**0.73**	-0.06	0.67	-0.33	0.21	-5.70
Marital status																	
Married (base)	1.00				1.00				1.00				0.00				
Not married	**0.79**	**0.04**	**0.63**	**0.99**	0.96	0.60	0.81	1.13	1.18	0.06	0.99	1.41	-0.01	0.92	-0.16	0.14	-0.78
Widowed	**0.55**	**<0.01**	**0.42**	**0.74**	**0.70**	**0.01**	**0.53**	**0.93**	0.96	0.82	0.67	1.38	0.06	0.74	-0.27	0.39	5.83
Children in household																	
No (base)	1.00								1.00				0.00				
Yes	**0.67**	**<0.01**	**0.51**	**0.88**	0.87	0.16	0.72	1.05	1.04	0.70	0.85	1.26	-0.08	0.34	-0.25	0.09	-7.87
Car/van available																	
Yes (base)	1.00				1.00				1.00				0.00				
No	**1.88**	**<0.01**	**1.53**	**2.31**	**1.61**	**<0.01**	**1.35**	**1.91**	1.07	0.47	0.88	1.30	0.16	0.07	-0.01	0.33	17.09
Area deprivation																	
Quartile one (least) (	1.00				1.00				1.00				0.00				
Quartile two	**0.65**	**<0.01**	**0.49**	**0.86**	**0.74**	**<0.01**	**0.60**	**0.91**	0.81	0.05	0.66	1.00	0.01	0.87	-0.17	0.20	1.51
Quartile three	**0.59**	**<0.01**	**0.44**	**0.79**	**0.78**	**0.02**	**0.63**	**0.97**	**0.78**	**0.04**	**0.62**	**0.98**	0.19	0.05	0.00	0.39	21.33
Quartile four (most)	**0.62**	**<0.01**	**0.46**	**0.83**	**0.71**	**<0.01**	**0.57**	**0.89**	**0.68**	**<0.01**	**0.54**	**0.86**	0.14	0.19	-0.07	0.36	15.44

6.6 Inequalities in relationships between Area Walking Potential and walking by socio-economic characteristics

This section describes differences in relationships between AWP and walking for people with different demographic, socioeconomic and household characteristics and for people living in areas with different levels of deprivation. The first section describes variation in walking outcomes between different groups in the fully adjusted regression models presented in section 6.4. Interactions testing was carried out to identify significant differences between the four AWP measures and four walking outcomes for each of the 9 covariate measures, a total of 144 models. Where significant interactions were found, the outcomes of stratified models are displayed and discussed.

6.6.1 The influence of demographic, SES, household characteristics and area deprivation in adjusted models

This section describes associations between covariate measures with walking outcomes. The purpose of this was to assess how these factors influence walking behaviour and influence relationships between AWP and walking. The data presented in this section is shown in the tables of adjusted regression models (Tables 43, 46, 49 and 52).

6.6.1.1 Demographic characteristics

In the adjusted models, the significant difference in likelihood of having achieved 30 minutes walking between females and males remained, with males 52% more likely to have done this than females in all models showing that sex has a significant impact on this outcome. There were no other significant associations between the sexes. After adjustment reduced odds of walking for older adults remained. There were significantly reduced odds of having completed a walk for adults in age groups 60-69 (62% decreased odds in all models) and 70+ (73% decreased odds in all models). For multiple walks, there were reduced odds of 23% in the 30-39 year age group, 32% in the 50-59 year age group, 53% in the 60-69 year age group and 65% in the 70+ year age group (66% for intersection density). In the same groups likelihood of having achieved 30 minutes walking ranged from 30 to 31%, 57 to 58% and 74 to75%.

6.6.1.2 Socioeconomic status

Evidence of a social gradient in walking outcomes remained in the adjusted models, whereby lower SES was associated with less walking. The strongest outcomes were for educational attainment where people with fewer qualifications did less walking. For people with no qualifications there were reduced odds of 58 to 59% for having completed a walk, 55 to 59% for having completed multiple walks and 44 to 46% for having achieved 30 minutes walking. For people with school level qualifications there were reduced odds of 35 to 36% for having completed a walk, 35% to 40% for having completed multiple walks and 35 to 37% for having achieved 30 minutes walking. There were also reductions of 20 to 24% for likelihood of having completed multiple walks for people with post-school qualifications only.

People who were unemployed were substantially less likely to have completed a walk (64 to 65%), multiple walks (44 to 46%) or achieved 30 minutes walking (55 to 56%) compared with people who were employed/in education. There were mixed outcomes for people classifying themselves as neither employed nor unemployed ('other'). People in this group had reduced odds of having completed multiple walks or having achieved 30 minutes walking. However, this group had higher predicted total minutes walking.

6.6.1.3 Household characteristics

Marital status still had a significant association with likelihood of having completed any or multiple walks in adjusted models. There were significantly reduced odds of 21 to 23% for likelihood of having completed a walk for people who were unmarried (except for the model controlling for residential density where there were reduced odds of 20%, p=0.05). People who were widowed were less likely to have completed any or multiple walks (reduced odds of 44 to 45% and 28 to 33% respectively). People who lived with children were less likely to have completed a walk (reduced odds of 32 to 34%). Not having access to a vehicle was associated with large increases in likelihood of having completed a walk (89 to 93%) and multiple walks (61 to 71%). However, lack of vehicle access was associated with an increase in total minutes walking (19.76 to 20.14%), although not when controlling for walkability.

6.6.1.4 Area deprivation

There was consistent evidence of associations between area deprivation and walking. Generally, people living in the least deprived areas walked more. There were reduced odds of having completed a walk for people living in quartiles 2 to 4 compared with people living in the least deprived quartile 1. There was no evidence of a consistent decrease in likelihood with increasing deprivation but decreases ranged from 33-41%. There were decreases in likelihood of having completed multiple walks with the strongest decrease in quartile 4 when controlling for destination accessibility (30%) and the weakest in residential quartile 2 (21%). Significant decreases were also observed for likelihood of having achieved 30 minutes walking in quartiles 3 and 4 ranging from 21% (quartile 3 when controlling for destination accessibility) to 34% (quartile 4 when controlling for residential density). However, there was some evidence of higher walking outcomes in more deprived areas for total minutes walking. For example, there was an increase in quartile 3 when controlling for residential density (24.80%) and intersection density (26.01%) compared with quartile 1.

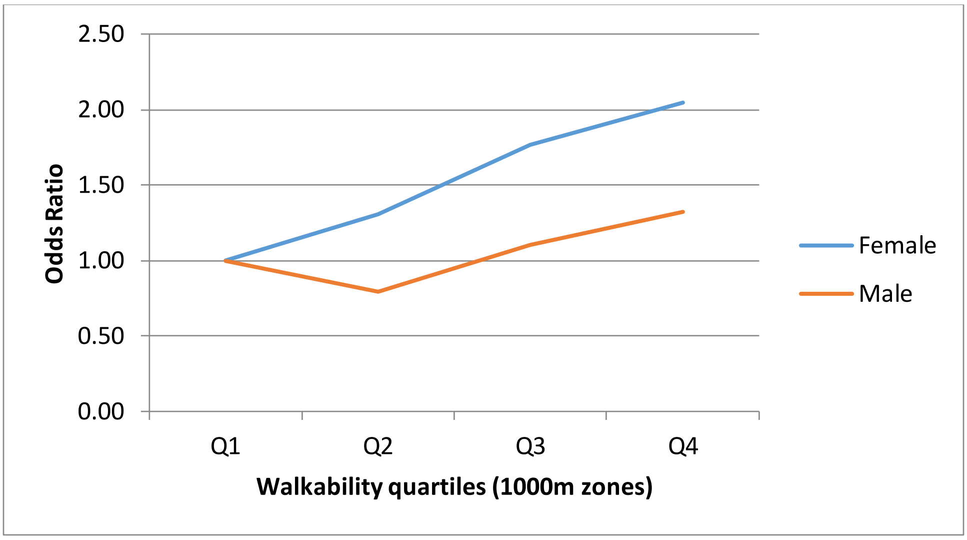
6.6.2 Variations in relationships between Area Walking Potential and walking by demographic, socioeconomic status, household characteristics and area level deprivation

This study tested for inequalities in associations between AWP and walking to see if different groups of people, or people living in different types of area. Interactions testing was carried out to test for significant differences in relationships by each of the covariates between AWP and walking for each measure of AWP and each walking outcome. Where significant differences were found, these are presented and discussed below. The numbers of people within each of the covariate categories in each AWP measure quartile were checked to ensure that low numbers would not cause problems for the analysis.

6.6.2.1 Demographic groups

In the fully adjusted model there were increased odds of having completed multiple walks for people living in walkability quartile 4 compared with quartile 1 (OR 1.67, Table 52). However, females more likely to have achieved this outcome than males (Figure 41) in all quartiles, with incremental increases between quartile 2 to 4 ranging from increased odds of 31% to 105%. By comparison males living in quartile 2 were slightly less likely to have completed a walk compared with those in quartile 1 (reduced odds of 21%) and only 32% more likely to have completed multiple walks in quartile 4. This suggests that women may be more sensitive to area walkability in their propensity to complete multiple walks than males.

Figure 41 Stratified analysis showing likelihood of having completed multiple walks, by walkability quartiles (1000m zones) and sex (n=4,456)

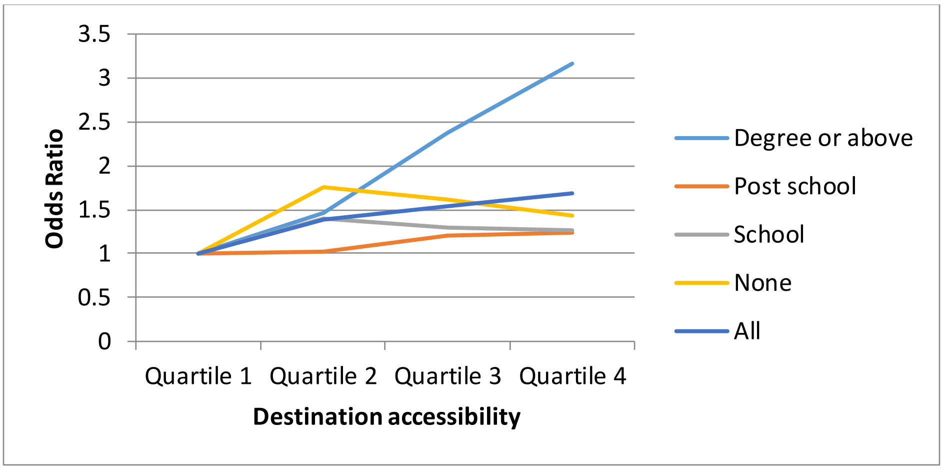


P<0.05

6.6.2.2 Socioeconomic groups

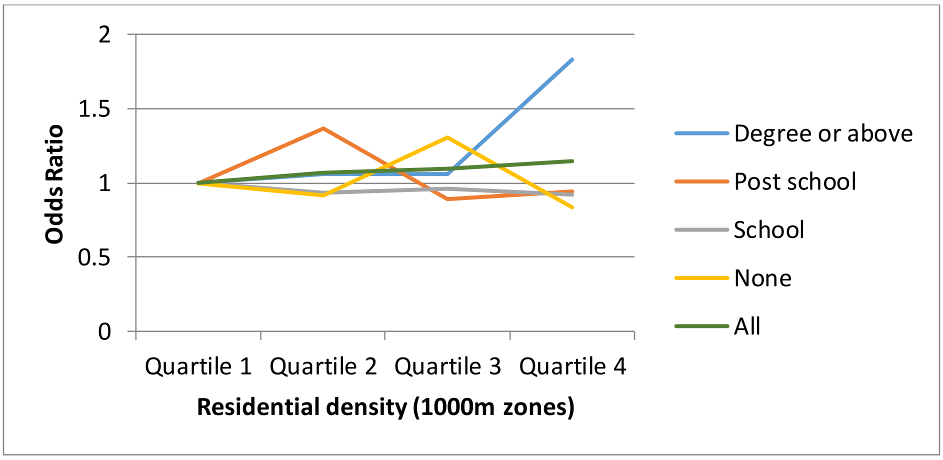
There were significant differences in relationships between AWP and walking between socioeconomic groups whereby people with higher individual level SES walked more in areas with higher AWP than people with lower SES. In the fully adjusted destination accessibility model (Table 43) there were incrementally increased odds of having completed multiple walks by destination accessibility quartile ranging from 39% (quartile 2) to 69% (quartile 4). However, the stratified analysis in Figure 42 shows that this increase was greater for people in the highest educational qualification category (degree or higher) with incrementally increased odds (1.46 in quartile 2 to 3.16 in quartile 4). There were incremental increases for people with post-school qualifications but these were smaller and ranged from 2 to 24%. The increases for people with school only or no qualifications were higher in quartiles 2 and 3 compared with quartile 4 showing no evidence of a dose-response relationship between presence of destinations and walking frequency. In fully adjusted models, there were significant increases in likelihood of having completed multiple walks for people living in residential density and intersection density quartiles 4 compared with quartile 1 (Tables 46 and 49). However, stratified models displayed in Figures 43 and 44 show that this was only the case for people with a degree or higher in residential density quartiles and that the increase was more pronounced in this group than for the others in intersection density quartiles. Overall these results show that destination accessibility is associated with increased likelihood of having completed multiple walks. However, people with higher individual level SES may be more sensitive to destination accessibility.

Figure 42 Stratified analysis showing likelihood of having completed multiple walks by destination accessibility quartiles (1000m zones) and educational attainment (n=4,456)



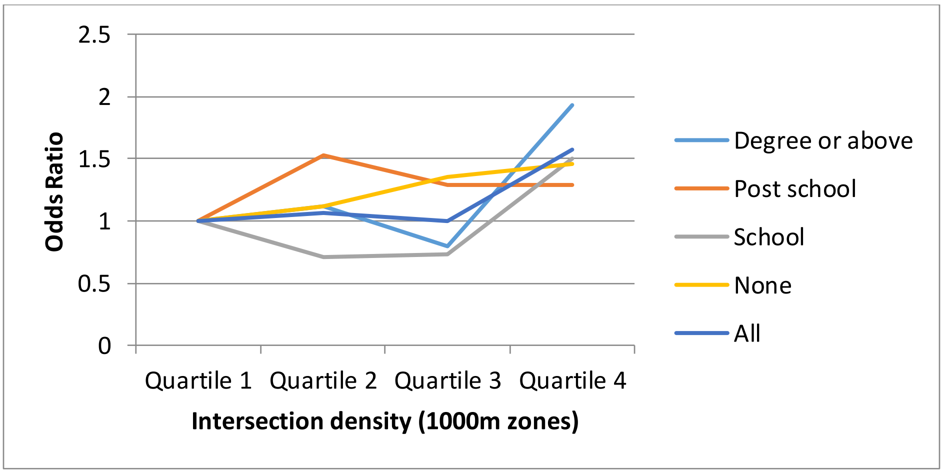
P=0.04

Figure 43 Stratified analysis showing likelihood of having completed multiple walks by residential density quartiles (1000m zones) and educational attainment (n=4,456)



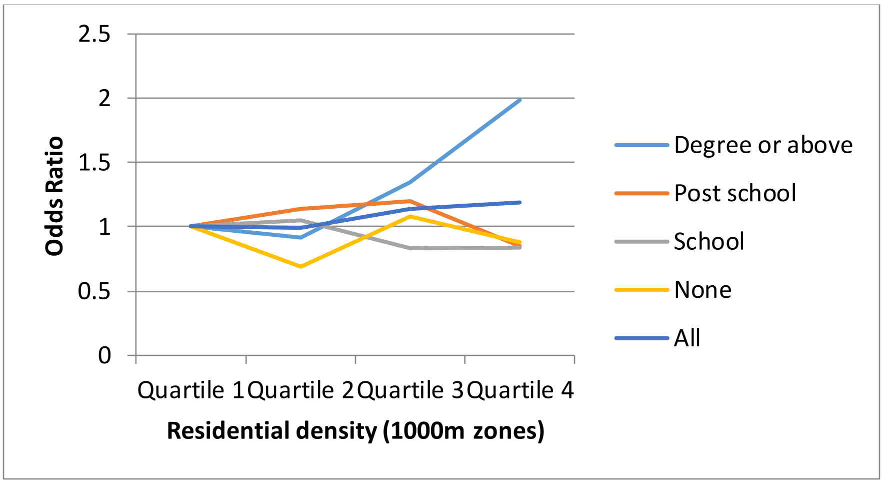
P= 0.04

Figure 44 Stratified analysis showing likelihood of having completed multiple walks by intersection density quartiles (1000m zones) and educational attainment (n=4,456)



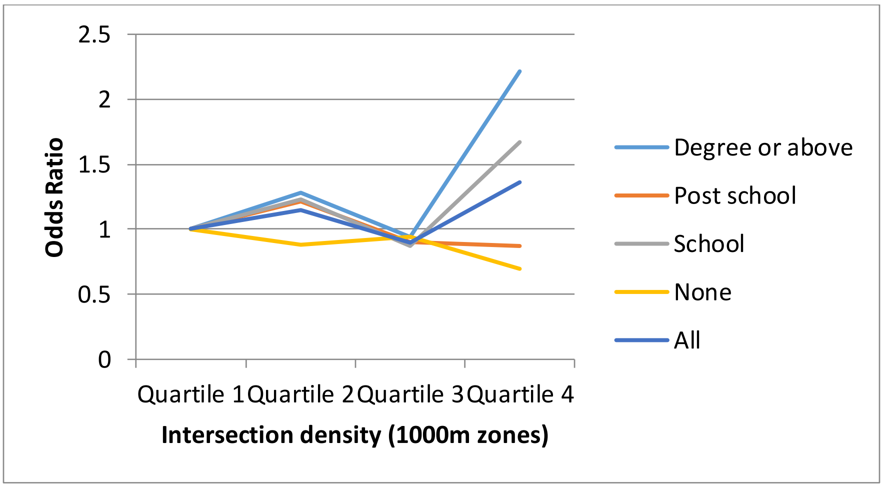
p=0.01

Figure 45 Stratified analysis showing likelihood of having achieved 30 minutes walking by residential density quartiles (1000m zones) and educational attainment (n=4,456)



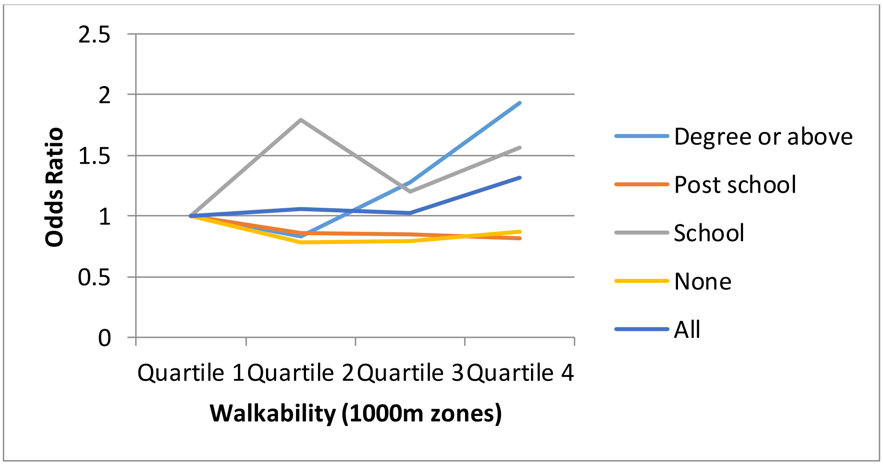
p= 0.01

Figure 46 Stratified analysis showing likelihood of having achieved 30 minutes walking by intersection density quartiles (1000m zones) and educational attainment (n=4,456)



P<0.01

Figure 47 Stratified analysis showing likelihood of having achieved 30 minutes walking by walkability quartiles (1000m zones) and educational attainment (n=4,456)

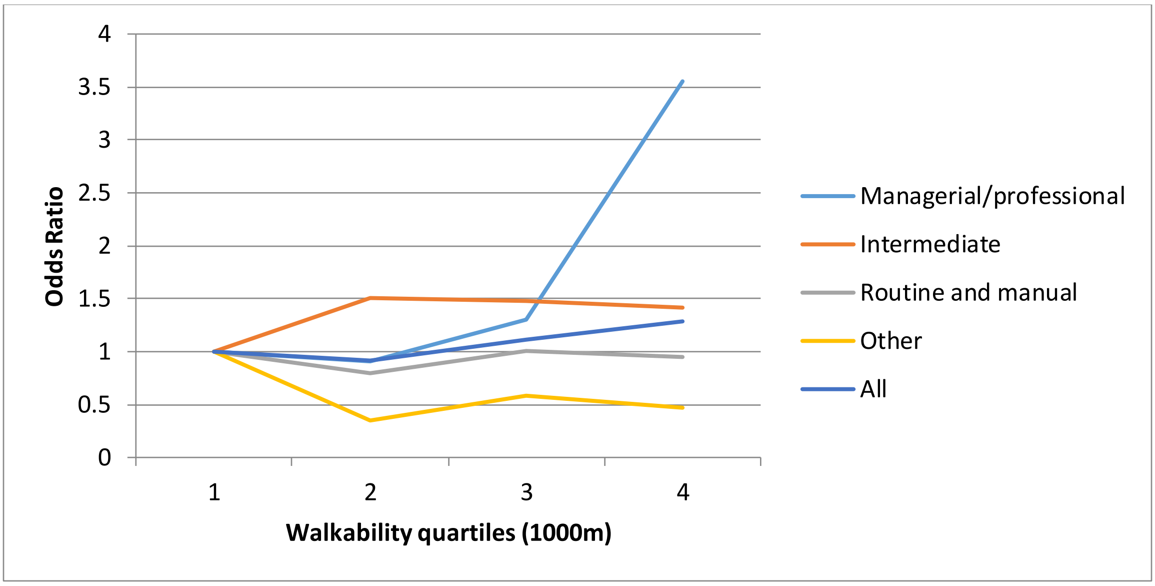


P<0.01

Figures 45 to 47 tell a similar story for likelihood of having achieved 30 minutes walking. Overall, there were no significant differences in likelihood of having achieved this for people living in different residential density quartiles. However, Figure 45 shows a large increase in odds (99%) for people with a degree or higher living in residential density quartile 4 but decreases for people with fewer qualifications. There were increases in likelihood of having achieved 30 minutes walking for people living in intersection density and walkability quartile 4 for people with qualifications (degree or higher, post-school or school qualifications), but not for people with no qualifications (Figures 46 and 47). People in the highest employment category living in quartile 4 were substantially more likely to have completed a walk than other groups with increased odds of 3.55 (Figure 48).

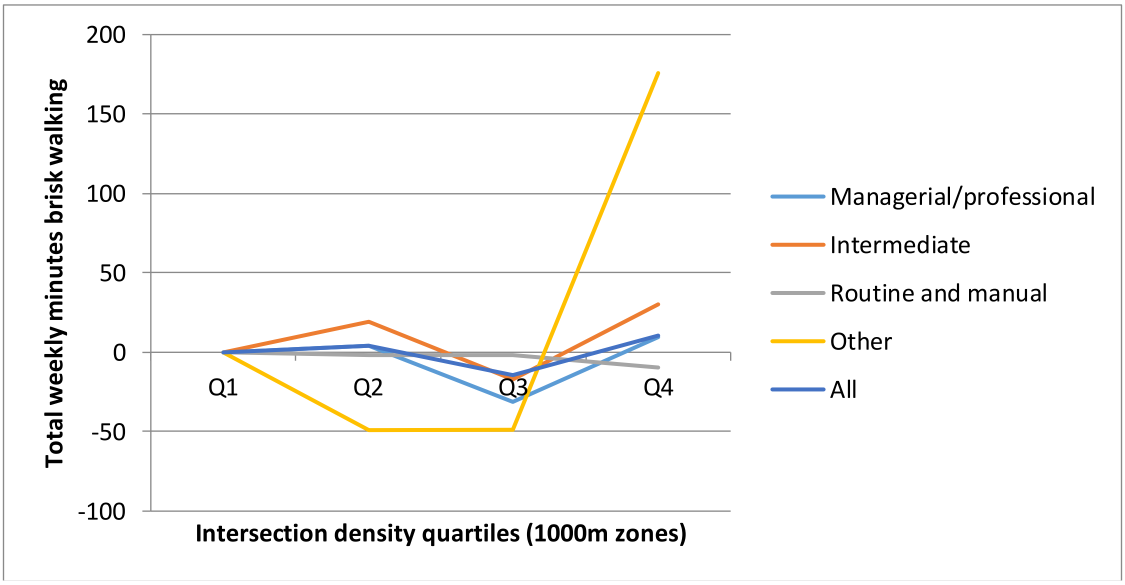
Trends for total minutes walking were less clear. People in the 'other' occupational category had much higher predicted walking minutes in intersection density quartile 4 (175.76%, Figure 49) compared with the predicted increase of 10.52% in minutes for all groups, but had predicted decreases in quartiles 2 and 3. Figure 50 shows there was a sharp increase in predicted weekly walking (109.87%) for people living in walkability quartile 2 compared with the overall predicted decrease (-1.50%) and higher outcomes for people who were neither employed nor unemployed than those in employment/education. It is possible that these results were spurious because the interaction models were only just significant at the 0.05 level (p=0.04535 P=0.0493 in Figures 49 and 50 respectively).

Figure 48 Stratified analysis showing likelihood of having completed a walk by walkability quartiles (1000m zones) and employment category (n=4,456)



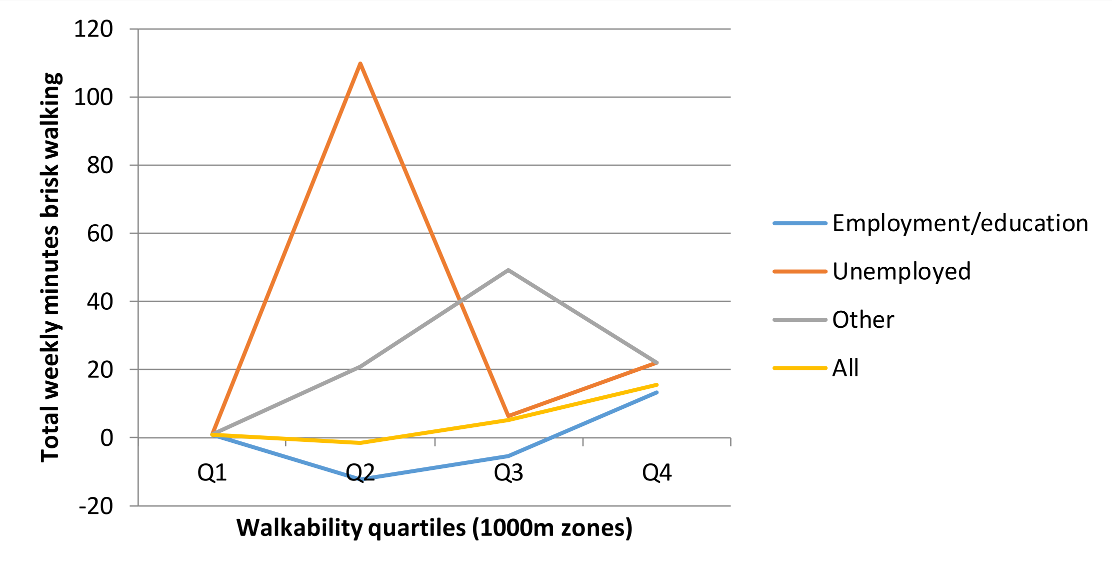
P<0.05

Figure 49 Stratified analysis showing predicted change in total weekly minutes brisk walking by intersection density quartiles (1000m zones) and employment category (n=1,460)



P<0.05

Figure 50 Stratified analysis showing predicted change in total weekly minutes brisk walking by walkability quartiles (1000m zones) and occupational status (n=1,460)



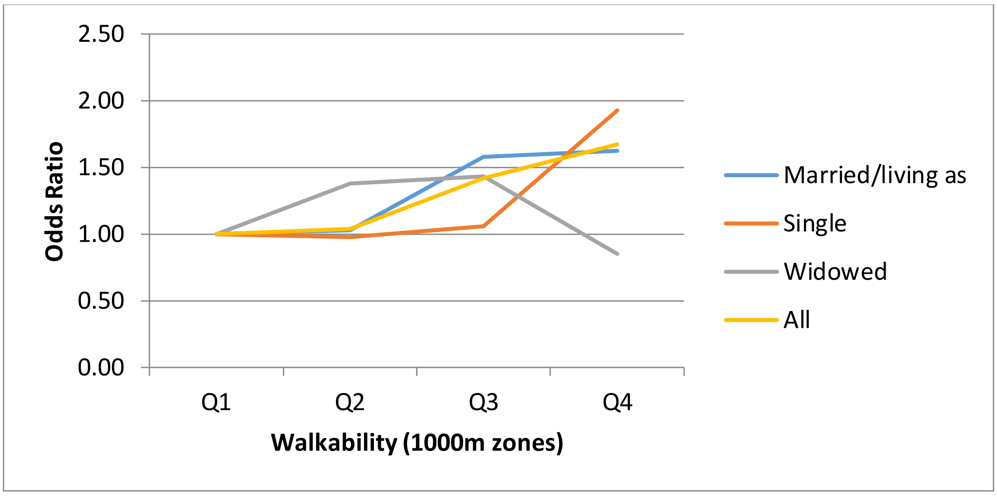
P<=0.05

6.6.2.3 Household characteristics

Marital status

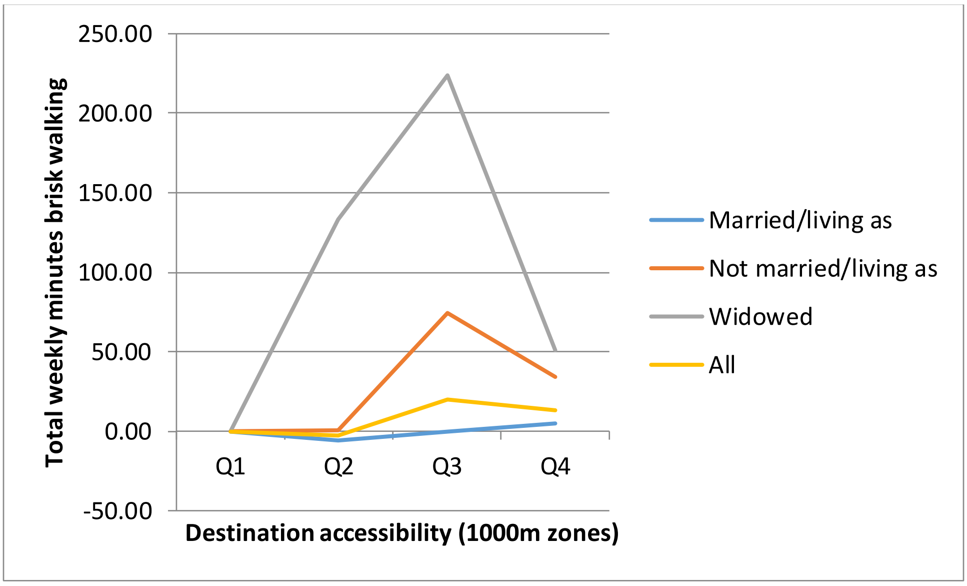
There were differences in relationships with AWP for people who are widowed, possibly because of lifestyle differences for this group. Figure 51 shows that the likelihood of having completed multiple walks for people who were widowed was higher than other groups in walkability quartile 2 (increased odds of 38%) but less likely than other groups to have completed a walk if living in an area classified as quartile 4 (decreased odds of 15%). There was little difference in likelihood of having completed multiple walks in walkability quartiles 2 and 3 for people who were single but this group were more likely than others to have completed multiple walks in quartile 4 (increased odds of 93%). Figure 52 shows inconsistent results for total predicted minutes walking, with widowers doing more walking in all destination accessibility categories, even in for people living in quartile 2 where destination accessibility was low. However, there was a larger increase in quartile 3 than other groups with a predicted increase of 223.84% compared with smaller increases for other groups, but then a smaller increase for those living in quartile 4. It is difficult to discern a trend from this inconsistent result but it does indicate that there may be differences in walking behaviour for this group which warrants further investigation.

Figure 51 Stratified analysis showing likelihood of having completed multiple walks by walkability quartiles (1000m zones) and marital status (n=4,456)



p= 0.03

Figure 52 Stratified analysis showing predicted change in total minutes brisk walking by destination accessibility quartiles (1000m zones) and marital status (n=1,460)

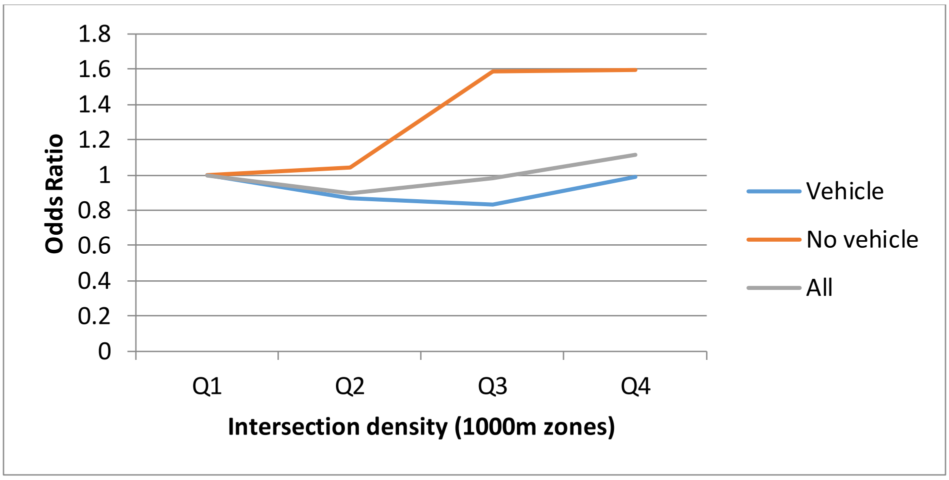


p<0.01

<u>Vehicle access</u>

People who did not have access to a vehicle were significantly more likely to have completed a walk and have achieved 30 minutes walking in higher intersection density quartiles than those who did not. Figure 53 shows increased odds of 4%, 59% and 60% in intersection density quartiles 2, 3 and 4 respectively compared with decreases for people who did not have vehicle access. This shows that while intersection density is likely to be particularly important for supporting propensity to complete a walk among this group without vehicle access.

Figure 53 Stratified analysis showing likelihood of having completed a walk by intersection density quartiles (1000m zones) and vehicle access (n=4,456)

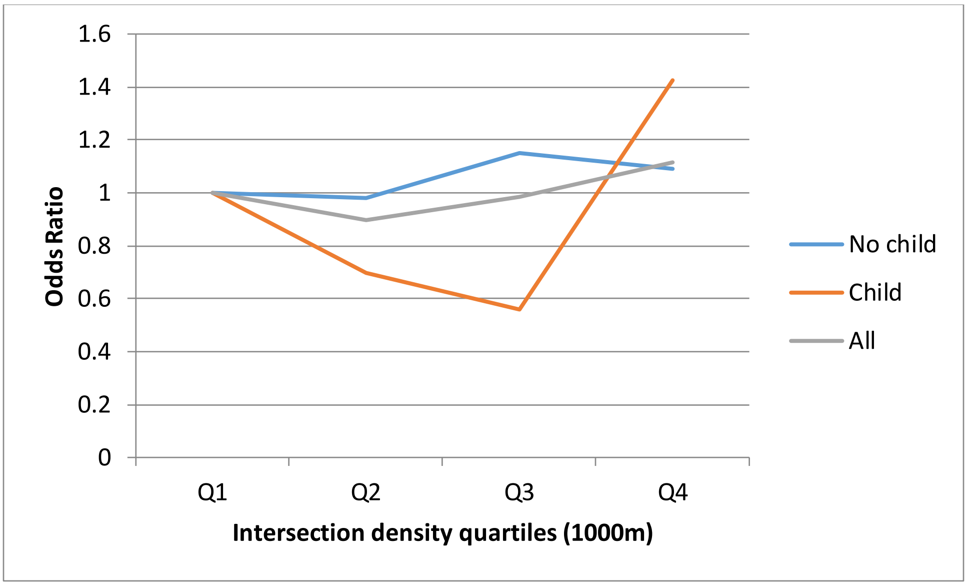


p= 0.0452

<u>Presence of children aged 2 to 15 years in household</u>

Figure 54 shows that for people living in a household where a child was present, likelihood of having completed a walk decreased sharply in intersection density quartiles 2 and 3 (reduced odds of 30% and 44%) compared with smaller decreases in quartile 2 and increases in quartile 3 and 4 for people who did have a child. There was an increase in likelihood of having completed a walk for people living in quartile 4 for all groups, but the increased was greatest for people living in a household with a child (increased odds of 43%). This is inconsistent trend may imply that areas with the highest intersection density are likely to encourage propensity to do any walking for people who have children compared with a decrease in likelihood of this group taking part in any walking in areas with lower intersection density.

Figure 54 Stratified analysis showing likelihood of having completed a walk by intersection density quartiles (1000m zones) and presence of children aged 2 to 15 years in the household (n=4,456)

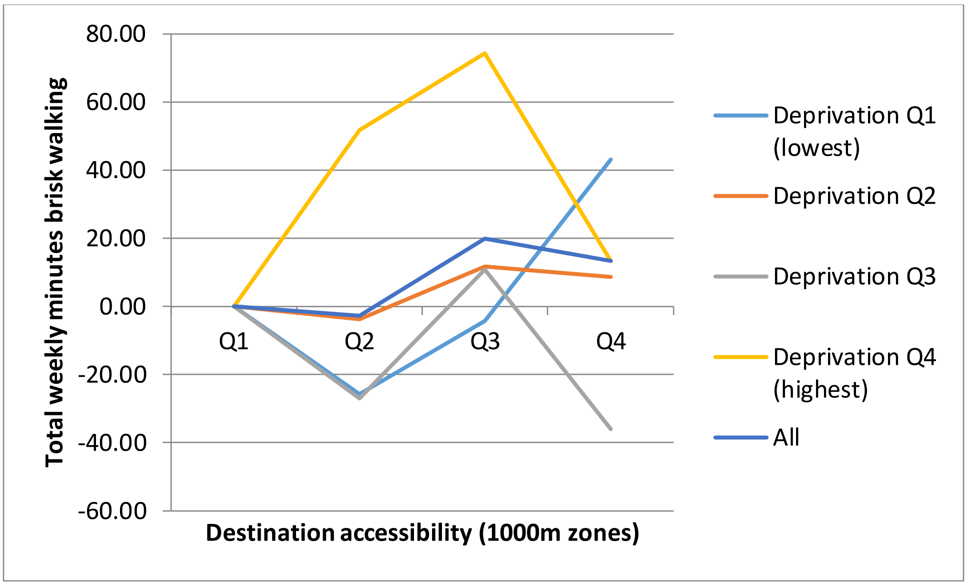


P= 0.0224

6.6.2.4 Area level deprivation

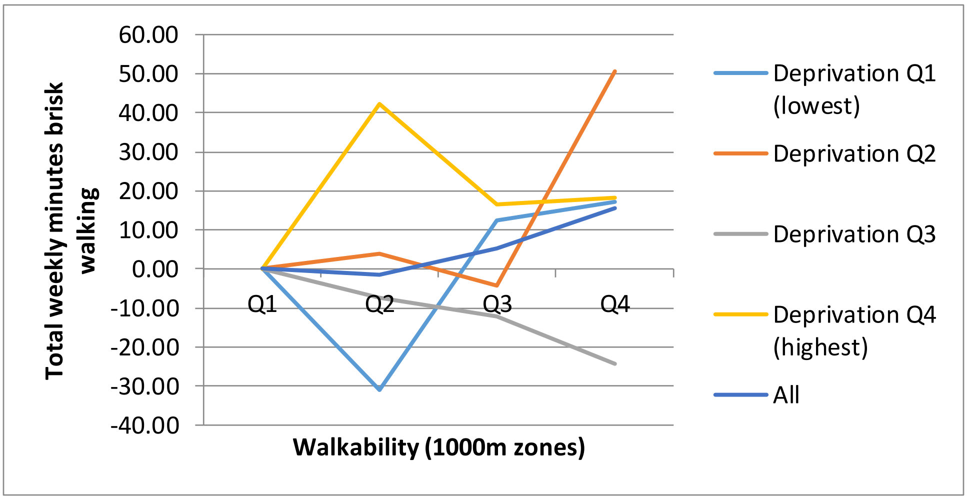
There were two significant interactions between AWP and total weekly minutes walking. In destination accessibility quartile 4 there was a jump in total minutes walking for people living in the least deprived quartile (Figure 55) and in walkability quartiles a jump for people living in deprivation quartile 2 (the second least deprived quartile) (Figure 56). It is possible that people living in the least deprived areas are the most likely to benefit by increased destination accessibility and walkability. However, this does not appear to be the case in areas with the highest levels of these two measures, where people living in areas with low deprivation walk the most.

Figure 55 Stratified analysis showing predicted weekly minutes brisk walking by destination accessibility quartiles (1000m zones) and area deprivation quartiles (n=1,460)



p=0.0157

Figure 56 Stratified analysis showing predicted weekly minutes brisk walking by walkability quartiles (1000m zones) and area deprivation quartiles (n=1,460)



p= 0.0275

6.7 Conclusion

This chapter addressed the aim of investigating relationships between neighbourhood-level measures of AWP with walking behaviour of residents in urban Scotland. It illustrates that there are associations between AWP with walking. There were substantial differences in these associations for different AWP measures, walking behaviour was more closely associated with levels of destination accessibility than the other three AWP measures. There were also patterns in outcomes by walking behaviour type with more consistent associations with likelihood of having completed multiple walks than the other walking measures (any versus no walking, walking to meet government PA recommendations and total time spent walking). Associations were generally found in areas with the highest AWP compared with the lowest. This suggests that people who walked more generally lived in areas with the highest level of AWP measures.

The second section addressed the aim of identifying inequalities in relationships between AWP and walking outcomes. There were significant associations between demographic, SES, household characteristics and area level deprivation with walking. Furthermore, associations between AWP and walking were unequal; people with different demographic, SES and household characteristics interacted differently with their walking environment. Notably, there was evidence of people with lower SES participating in less walking in relation to AWP than people with higher SES. There was some limited evidence of an area effect suggesting that area deprivation may also impact on walking behaviour in relation to features of the AWP.

The next chapter will discuss these findings together with the results from Chapter 5, the social spatial distribution of AWP. It will address explanations for these findings and their potential policy implications.

Chapter 7. Discussion

7.1 Introduction

7.1.1. Summary of the research and chapter outline

The research examined associations between neighbourhood built environment measures of Area Walking Potential (AWP) and walking behaviours of residents, as well as inequalities in these relationships. It has generated unique evidence and made a fresh contribution to the international literature about these relationships.

The research has considered the distribution of AWP measures across Scotland and in relation to area deprivation, to see whether there were geographic inequalities in access to AWP. The research examined associations between the AWP and walking behaviours of people living in each neighbourhood, to determine whether differences in neighbourhood AWP resulted in differences in walking. Couched in social ecological theory, this work further considered inequalities in relationships between the AWP with walking outcomes, and whether these were influenced by factors operating at different levels, such as individual of demographic, socioeconomic and household characteristics and area level deprivation.

This chapter discusses the findings of the study in relation to the research aims. Initially a summary of the key findings is provided followed by a detailed discussion and possible explanations for the findings and what the research adds to the literature.

7.1.2 Key findings from the research

- AWP was geographically unequal across urban Scotland. There were geographic concentrations of high AWP surrounded by lower AWP.
- There were some positive associations between AWP and walking indicating potential of AWP to support walking.
- There were inequalities in relationships between AWP measures and walking behaviours for people with different individual characteristics, showing that different groups interact differently with AWP.
- Areas with the least deprivation had lowest AWP. However, people living in deprived areas walked less. Conversely, people living in the least deprived areas walked more.

- Some groups whose individual characteristics were typically associated with lower levels of walking walked more in areas with higher AWP. This highlighted the potential of neighbourhood AWP to support walking among diverse groups in urban Scotland and potentially reduce health inequalities in walking outcomes.
- Some groups of people who walked less were less likely to walk more in areas with higher AWP. This showed that not everyone benefits equally from increased AWP.

7.2 Creating small area measures of Area Walking Potential considered to influence walking in urban Scotland

This section will discuss the results of the research aim:

To create small area measures of features of the built environment with the potential to influence walking behaviour for urban Scotland

Four key measures of the built environment were created to measure neighbourhood Area Walking Potential (AWP) across urban Scotland. These were 1. Destination accessibility, 2. Residential density, 3. Street connectivity and 4. Walkability. These measures were selected using theoretical and empirical evidence of their influence on walking. The measures were created with careful consideration of how evidence from elsewhere in the world might be applicable in the Scottish urban context and to Scotland's demographic composition. This was the first study to create GIS measures of AWP across the whole of urban Scotland and therefore provides important demonstration of the feasibility of using secondary data to create small area measures of AWP over a large area.

Testing associations between the four AWP measures with walking meant comparisons could be made between the strength of associations between these different measures and conclusions drawn about the relative strength of their associations with walking. While much of the existing literature only distinguishes between high or low levels of AWP measures, this study used four categories for each measure (high, medium-high, medium-low and low). This provided more detailed insight into relationships between AWP measures and walking This is one of few walkability studies that considered whether each of the component measures of walkability have associations with walking as well as the composite measure. It is important to unpack the relative influence of component measures on walking as well as to understand the composite influence to ensure that the composite measure includes features of the BE that are likely to support walking. By comparing each of the component walkability measures as well as the combined measure this study tested the independent contribution of each measure and compares this with the synergistic influence of the composite measure. In so doing, this study challenged what is frequently an uncontested acceptance of walkability metrics, which are developed and applied without theoretical or empirical interrogation (Van Dyck et al., 2010). This shows that walkability indices may need to be specifically adapted to different contexts rather than re-used based on research undertaken elsewhere.

7.3 Associations between neighbourhood level measures of Area Walking Potential with the walking behaviour of residents of urban Scotland

This section addresses the thesis aim:

To investigate relationships between neighbourhood-level measures of the built environment with walking behaviour of local residents in urban Scotland.

7.3.1 Destination accessibility

Walking outcomes were more strongly associated with destination accessibility than the other measures of AWP. The strongest result was the dose-response pattern observed between increasing destination accessibility and likelihood of having completed multiple walks. There were incremental increases in likelihood of having completed multiple walks with increasing destination accessibility and people living in areas with the highest level of destination accessibility were 69% more likely to have completed a walk. This suggested that propensity to complete multiple walks is sensitive to incremental increases in destinations available within walking distance. The implication is that small changes to destination accessibility may be associated with increased walking among those who are active walkers already. When comparing whether people had walked or not, the study found that people were 46% more likely to have completed any walks if they lived in areas with the highest levels of destination accessibility compared with people living in areas with lowest destination accessibility. There were no significant differences in likelihood of having completed any walks for people living in areas with medium-low and medium-high levels of destination accessibility. This result implied that people who did not complete any walks may not be influenced by small increases in destination accessibility. The implication is that different aspects of AWP may affect different kinds of walking behaviour and different kinds of people to a differing extent; built environment interventions will not have uniform impacts.

The study suggests then that destination accessibility is important for supporting walking in Scotland. It is congruent with the wider literature which has found consistently positive results for destination accessibility, with stronger associations between walking (particularly travel walking) with destination accessibility than for other built environment measures (Panter and Jones, 2010; Saelens and Handy, 2008). The measure created for this study was based on the National Destinations Accessibility Index (NDAI) created by Witten et al. (2011). It comprised eight domains of destination types and each category was allocated a score based on the presence or prevalence of destinations within each domain. This is a more complex measure than some other types of destination accessibility measures. Other approaches to calculating destination accessibility include a score based on presence or absence of different types of destination or simply counting the number of destinations. The more complex measure used in this study takes account of both prevalence and diversity of destinations and differentiates where access to more than one destination is likely to encourage walking more than access to a single destination. This was particularly suited to this study since this study covered a wide geographic area (across urban Scotland) and a diverse demographic sample representative of the Scottish population. This measure that was sensitive enough to capture diverse destinations that exist across Scotland as well appeal to the variety of people in the study. These results also add to international evidence showing the suitability of the NDAI as a basis for measuring destination accessibility.

7.3.2 Residential density

After adjusting for covariates, no significant associations remained between residential density and any of the walking outcomes. To an extent this was surprising because of the strong associations found in some studies between residential density and walking although other evidence reported weak or null effects. The reasons for the lack of associations found in this study and contrasting findings in other research may be complex. One potential reason is differences in outcomes for different types of walking (i.e. the purpose of the walk). Other literature generally found positive associations between population density and walking for transport (Saelens and Handy 2008, McCormack and Shiell 2011, Grasser et al. 2013, Forsyth et al. 2007) but not with leisure walking (Forsyth et al. 2007, Panter and Jones 2010, Saelens and Handy 2008, McCormack and Shiell 2011, Rydin et al. 2012). Thus, the lack of associations in this study may be partly because it did not distinguish between different types of walking which may have resulted in a 'zero sum game' where positive associations with travel walking were tempered by a lack of association with leisure walking. Differentiating between people's motivations for walking may give a clearer picture of associations with residential density.

In a study spanning 12 countries including the UK, Sugiyama et al. (2014) found evidence of a threshold effect in the relationship between perceived residential density and leisure walking, with greater perceived residential density associated with increased walking up to a point, but less walking for areas rated with the highest residential density scores. This 'threshold effect' may indicate that very high residential density is less conducive to walking, for example, dense or high-rise flats may create a less appealing walking environment. However, mean residential density in the UK was lower than most of the countries included in this study (fourth lowest) so it is possible that the threshold limit was not present in the UK. There was no evidence of a threshold effect in the results of this study, since associations with walking outcomes in places with medium-low and medium-high were not higher than those in areas with high residential density. This may be because UK residential density is not generally high enough to discourage walking.

One of the reasons that residential density is thought to support walking is that it implies the presence of amenities, destinations and the creation of an interesting and diverse landscape (Lake and Townshend 2006, Turrell et al. 2013). Residential density in itself may not support increased walking but may need to exist in conjunction with other environmental attributes that contribute to AWP (Filion et al. 2006; Forsyth et al. 2007).

As discussed in Chapter 2, there are substantial variations in the ways in which features of the built environment are conceptualised and measured. Residential density is measured both as number of people per land area (population density) and number of residential units per land area (housing unit density) (Forsyth et al. 2007). These definitions are sometimes used interchangeably (Moudon et al. 1997; Filion et al. 2006) giving the misleading impression that they measure the same thing. This makes it difficult to identify which environmental attribute is actually associated with increases in walking (Forsyth et al. 2007). Additional ambiguity arises since most studies categorise areas based on levels of density, rather than discussing actual measurements.

This makes it difficult to compare outcomes between studies or know what levels of density are associated with walking.

Finally, most research has been carried out in the US and Australasia which has lower residential density than the UK and most European countries (Townshend & Lake 2009; Giuliano & Narayan 2003). For example, a study by Giuliano & Narayan (2003) found that the effect of density on daily travel trips was more pronounced in the US than in Great Britain, which might explain the lack of associations found in this study compared to studies carried out in the US.

7.3.3 Street connectivity

There were significant increases in the likelihood of having completed multiple walks (57% increased odds) and likelihood of having achieved 30 minutes walking (36% increased odds) for people living in areas with the highest intersection density (compared to the lowest). There were no associations with likelihood of having completed any walks or total minutes walking. Overall there were very limited associations between intersection density with walking, suggesting it was not strongly important for supporting walking. In other studies, positive associations have been found between street connectivity and walking (Grasser et al. 2013; McCormack & Shiell 2011; Sugiyama et al. 2012; Eriksson 2013; Knuiman et al. 2014; Turrell et al. 2013; Kaczynski 2010; Witten et al. 2012; Badland et al. 2008; Fan et al. 2014; Sugiyama et al. 2009; Sugiyama et al. 2014; Wells & Yang 2008; Heinrich et al. 2007). However, others report weak or null effects (Panter & Jones 2010; Saelens & Handy 2008; Koohsari et al. 2014; Geddes & Vaughan 2014). As discussed in Chapter 2 there are substantial variations in the ways in which street connectivity is conceptualised and measured and so some of these differences may be due to differences in methods used to measure intersection density. This study used a measure of connectivity that considered the number of true intersections per land area. However, some have argued that there are other nuances of street connectivity that are important such as configuration of the streets not just the number of intersections (Marshall et al. 2014). It is possible that a measure that captured such aspects of street connectivity may have shown stronger associations. Additionally, as with residential density, most studies use ranked, rather than absolute, intersection density scores making it impossible to compare strength of associations between studies effectively and to know what levels of intersection density have been associated with walking in previous studies.

Most studies into connectivity have taken place in the US and no other evidence was found relating specifically to Scotland. It is also possible that street patterning in the Scottish context is substantially different from that of elsewhere such as in the US, which may account for the weaker results found in this study. In the US, for example, sprawling suburban neighbourhoods are often disconnected with high levels of cul-de-sacs compared with the UK (Lake & Townshend 2006). It is possible that the lack of associations found in this study may be because there is not enough variation in connectivity in urban Scotland to show strong associations with walking. It may even reflect a positive situation whereby street connectivity in urban Scotland is consistently adequate to support walking. Without comparable data on absolute connectivity measurements from other studies it is difficult to make firmer judgments beyond these speculations.

As with residential density, the weak results found in this study may be partly due to a lack of differentiation between people's motivations for walking. Understanding more about why people walk may give a clearer picture of the ways in which built environment affects walking since stronger associations were found between intersection density with walking for transport than walking for leisure in previous literature (Saelens & Handy 2008; Grasser et al. 2013; Sugiyama et al. 2012; McCormack et al. 2012). Again, this may result in a 'zero sum game' for walking outcomes, where null associations are found due to positive associations with transport walking and negative or negligible associations with leisure walking, resulting in no net increase in walking. Alternatively, a zero sum game may result because better connectivity is associated with greater ease of navigation but may also be associated with increased vehicle traffic (Pearce & Maddison 2011), which may discourage walking because of safety fears, and preferences for quieter streets. Finally, others have suggested that the positive associations between street connectivity and walking may be a result of confounding by other features of AWP such as destination accessibility or diversity (Koohsari et al. 2014; Geddes & Vaughan 2014).

7.3.4 Walkability

A measure of walkability was created by combining the measures of destination accessibility, residential density and intersection density. The rationale behind a combined walkability metric is that it has the potential to reflect multiple facets of AWP that might influence walking. Since people perceive and experience different features of their environment simultaneously this is considered to offer a more comprehensive measure of the environment than single BE measures. Different aspects of the BE will appeal to or inhibit people differently, therefore using a combined metric may capture multiple features of the BE that are important for walking. Additionally, features of the BE that support walking are likely to have a stronger influence on behaviour when present in combination with others, for example, good street connectivity is more likely to support walking when there are destinations present for people to walk to.

The results of this research showed significant increases in likelihood of having completed multiple walks for people living in high walkability areas (67% increased odds) and a smaller increase for having achieved 30 minutes walking (32% increased odds). There were no associations for likelihood of having completed a walk or total minutes walking. Other literature has consistently found positive associations between measures of walkability with walking for transport and active travel, with evidence from the US (Bracy et al. 2014; Frank et al. 2005; Frank et al. 2010; Freeman et al. 2013; Oluyomi et al. 2014; Vargo et al. 2012), Canada (Clark et al. 2014; Manaugh & El-Geneidy 2011; McCormack et al. 2012; Thielman et al. 2015) Brazil (Reis et al. 2013), Sweden (Eriksson et al. 2012; Sundquist et al. 2011) and Belgium (Van Dyck et al. 2011). Weaker or null associations have been found for leisure walking (Sundquist et al. 2011; Thielman et al. 2015; Reis et al. 2013).

These limited associations between walkability and walking in this study is likely to be due to the weak associations found with residential density and street connectivity which were included in the measure of walkability. This shows the importance of constructing a walkability index using evidence-based measures of the BE that have been found to be associated with walking. This would then be useful for policy makers as a guide for measuring and creating neighbourhoods that are supportive of walking.

In the international literature combined walkability metrics are frequently re-used. For example, a combination of street connectivity, residential density and Land Use Mix (Frank et al. 2005; Manaugh & El-Geneidy 2011; Van Dyck, Cardon, Deforche, Owen, et al. 2011; Reis et al. 2013; Sundquist et al. 2011; Oluyomi et al. 2014) and the index developed by Frank et al. (2010) which also includes a measure of Retail Floor Area Ratio (RFAR) (Bracy et al. 2014; King & Clarke 2015; Frank et al. 2010; Salvo et al. 2014). Unquestioned re-use of such metrics without testing the component measures could result in the use of measures that are inappropriate in different contexts, which in turn could obscure associations with walking behaviours. This study has shown the importance of testing the components of walkability indices, and has shown that in this urban Scottish context, different component measures of the walkability metric had substantially different associations with walking.

7.3.5 Associations between Area Walking Potential with different walking outcomes

This research compared associations between AWP and four different walking outcomes: likelihood of having completed any walks of at least ten minutes in the previous four weeks; likelihood of having completed multiple walks of at least ten minutes in the previous four weeks; likelihood of having walked for 30 minutes or more in bouts of at least ten minutes on any day in the previous four weeks; and total minutes spent walking briskly in the previous week. Associations with likelihood of having completed multiple walks showed the strongest relationships with AWP measures. There were some associations with AWP measures and likelihood of having completed any walks but these were more limited and weaker. There were limited associations with achieving 30 minutes walking and no associations with total minutes brisk walking.

These findings echo other literature finding positive associations between AWP and frequency of walking (Berke et al. 2007; Freeman et al. 2013) and for likelihood of any walking found in the US (Freeman et al. 2013), Canada (McCormack et al. 2012) and Sweden (Sundquist et al. 2011). Previous studies also found positive associations with total time spent walking from the same countries (McCormack et al. 2012, Forsyth et al. 2009, Nagel et al. 2008, Sundquist et al. 2011). Some research considered more than one type of walking outcome, for example, studies by McCormack et al. (2012) and Sundquist et al. (2011) found positive associations for both frequency and total walking time. However, there is generally little existing evidence comparing different walking outcomes and this, therefore, marks an important contribution of the study.

The strong associations found for likelihood of doing multiple walks in this study may indicate that among people who do walk, the amount of walking may be significantly increased by higher AWP. However, it also appears that AWP may have only limited potential to influence whether people walk or not. Socioecological models of health show that influences on walking are multifaceted and the potential of the built environment is one of multiple different types of influence on walking. For example, people who are not likely to do any walking of ten minutes or more may be inhibited by other factors such as perceptions of their environment, social or cultural influences or may face restrictions on their time such as long work hours and family commitments. A report into attitudes to walking and cycling found that the three main reasons why people did not walk or cycle were fears for safety, the difficulty of fitting walking or cycling into complex household routines (especially for people with young children) and perceptions that walking or cycling were 'abnormal things to do' (Pooley et al. 2011). Such barriers are not easily breached or affected by the built environment, which may explain some of the weaker associations found for this walking outcome in this study. The limited associations for people walking for 30 minutes or more may be because people who take longer walks do so outside of their neighbourhood, making associations with neighbourhood measures weak (Learnihan et al. 2011). The lack of associations with total minutes spent walking may be because this measure only reflected brisk walking and walking speed is not necessarily influenced by the built environment. This outcome was a derived variable in the Scottish Health Survey which was calculated based on several assumptions discussed in Chapter 4 and on subjective assessments of walking speed. These assumptions and issues may have limited the potential of this variable to reflect associations with AWP.

The results of this study support the argument that different types of walking behaviour may be influenced differently by built environments (Alfonzo 2005). This makes an important contribution to the literature since many studies consider only one type of walking outcome but this study shows that there can be considerable variation for different types of walking behaviour. It is important to be aware of the differences in associations with different walking outcomes when considering how to support walking in urban Scotland, and the role that the built environment can play.

7.3.6 Different size zones - Neighbourhood area geography

This study used two neighbourhood size zones to make comparisons between AWP and walking, 500m and 1000m buffer zones around population-weighted centres of Scottish Output areas. These zone sizes were selected based on theoretical and methodological consideration of the walking outcomes of interest discussed in Chapter 4. Two area geographies were used for neighbourhood zones because there is uncertainty surrounding the most appropriate exposure zone for measuring associations between AWP and walking outcomes and there have been calls for further evidence in this area (Cummins et al. 2007; Diez Roux & Mair 2010; Kwan 2012). The inclusion of two zone sizes acted as a sensitivity analysis for associations between AWP and walking in urban Scotland. Associations were stronger using 1000m zones which supports other evidence finding 1000m buffer zones as an appropriate geography for finding positive associations between AWP and walking (for example, Berke et al. 2007; Frank et al. 2005; Lee & Moudon 2006; Salvo et al. 2014). However, there is also evidence that the strength of associations between AWP and walking when comparing geographic exposure zones varies for different AWP measures (Berke et al. 2007; Villanueva et al. 2014; Nagel et al. 2008) and so different AWP measures may be better assessed using different exposure zones. In this study, weaker results were found using 500m zones. This may be because 1000m may better capture people's typical activity space; people may be more likely to walk up to 1000m as part of their neighbourhood walking than restrict walking to 500m. Alternatively, the lack of association at 500m may be because the walking outcomes in this study focussed on walks of ten minutes or more and 500m may be too small to capture walks of ten minutes (McCormack et al. 2012). Other studies support the possibility that measuring environments and / or amenities in zones smaller than 1000m leads to null or negative associations with walking. For example, in their study of older adults in Australia, Nathan et al. (2012) found that access to medical care services within 400m (OR = 0.77, 95% CI = 0.63-0.93) and 800m (OR = 0.83, 95% CI = 0.70-0.99) reduced the odds of sufficient walking.

Some authors have suggested that there may be differences in the most appropriate geographic neighbourhood zone for different groups of people, in particular older people are considered likely to stay closer to their homes than younger adults (Day 2008) and thus have a smaller walking area. Bracy et al. (2014) found stronger associations between GIS measured AWP and PA using 50m neighbourhood zones than 1000m zones in their study of older adults aged 66+ years. However, there were no consistent trends between groups by different buffer sizes. This is somewhat surprising since it seems intuitive that some groups, such as older adults may have smaller walking areas and therefore different size zones would be important for different people but the results indicate that this was not the case for the respondents in this study sample.

7.4 Inequalities in associations between Area Walking Potential and walking by individual characteristics

This section addresses the following thesis aim:

To identify inequalities in relationships between built environment measures and walking for people with different sociodemographic characteristics (such as age and individual socioeconomic status) and for people living in different types of area.

7.4.1 Inequalities in associations between Area Walking Potential and walking by individual characteristics

There was evidence that AWP might matter in different ways to different groups. Increasing walkability was associated with increases in completing multiple walks, however, this increase was significantly more pronounced for women than men. This may point to greater sensitivity to walking environments among females than males. One possible reason for this is that women are less likely to be in full-time employment and more likely to take responsibility for childcare than males (Equality and Human Rights Commission 2015). Ellaway & Macintyre (2001) found that gender differences in perceptions of neighbourhoods related to domestic circumstances, suggesting that women at home with children may be more exposed to, or sensitive to, features of their environment than people in employment. This is likely to be because caring for children often involves spending more time locally and making trips to local resources such as parks, play centres and leisure centres. Other literature has found some evidence of higher physical activity with increased street connectivity for females than males (Forsyth et al. 2007, Boone-Heinonen and Gordon-Larsen 2011) but found no evidence of differences in walking outcomes (Troped et al. 2010, Owen et al. 2007, Nathan et al. 2012). This study offers some evidence of differences in relationships between AWP and walking for women which has received little attention in other research.

Age was strongly and inversely associated with walking outcomes, with decreased odds of having completed any or multiple walks or 30 minutes of walking with increasing age for older adults. This finding is supported by previous evidence both in Scotland (Brown et al. 2014) and elsewhere including Australia (Nathan et al., 2012) showing older adults walk less than younger adults. Analysis of associations between AWP and walking stratified by age group, however showed no significant variations by age. This shows that positive relationships between AWP and walking found have the potential to support walking among adults of any age. This is particularly important because older adults have been identified as a group who may benefit most from improvements in their local environment since their mobility may be more restricted than other groups and therefore reliance on neighbourhood environments may be greater (Day 2008) and walking is also a popular form of PA for this group (Nathan et al., 2012). Thus, improving AWP may be a mechanism supporting walking among older adults overall.

These results show that the BE, as captured in the measures used in this study, might have some influence on walking among the Scottish population, including those groups who are less likely to take part in physical activity such as older adults. For other groups, such as women or people who living in households where there are children present, high AWP may be particularly important for supporting walking because these groups may be more exposed, or sensitive to, their environment. There is evidence to show that people who experience greater exposure to their neighbourhood environment experience stronger associations between their neighbourhood BE and physical activity (Ivory, Blakely, et al. 2015). This shows it is possible that AWP may help to ameliorate health inequalities associated with lack of PA, since high AWP can support walking among groups who are less likely to walk or take part in physical activity overall.

7.4.2 Inequalities in associations between Area Walking Potential and walking by individual socioeconomic status

There were differences in relationships between AWP and walking for people with different SES. For example, the increases in likelihood of having completed multiple walks in areas with higher destination accessibility were significantly higher for people with higher educational qualifications. There were no significant associations between residential density and walking outcomes in overall models, stratified models revealed that there were increases in likelihood of having completed multiple walks and 30 minutes walking with increasing residential density for people with a degree or higher. There were also higher walking outcomes for people who were employed/in education and those in the highest employment category. It likely that this reflects a social gradient in responsiveness to the BE, since education is used as a proxy for SES (D'Haese et al. 2014).   This is important because it shows that people with lower SES, particularly less well qualified groups, may be less likely to walk more in areas with high AWP. This is supported by other research finding stronger associations between walkability and transport walking (Owen et al. 2007) and access to facilities and PA outcomes (Pan et al. 2009) for people with higher educational attainment. This may be due to different perceptions and attitudes among lower SES groups. Gebel et al. (2009) found that adults with lower educational attainment and lower incomes were more likely to perceive objectively measured high walkable neighbourhood as low walkable in their Australian study. Pan et al. (2009) suggest a possible reason for higher PA outcomes among people with higher educational attainment is that this group is more likely to perceive the benefits of choosing to walk and are therefore more likely to have a positive intention to walk. In addition, the authors found positive associations between education and self-efficacy (confidence in personal ability to carry out a behaviour) and that this meant that people were more likely to carry out their intention to take part in PA. The authors surmised that perceptions of environmental attributes may be more strongly correlated with cognitive antecedents and with behaviour than are objective measures.

7.4.3 Inequalities in associations between Area Walking Potential and walking by household characteristics

People who had one or more children in their household were more likely to have completed a walk if they lived in areas with the highest intersection density but less likely in areas with low or moderate intersection density. This study and other literature has found that the presence of children in the household was inversely associated with propensity to have completed a walk. Qualitative research investigating attitudes to walking has found evidence that people who have children may in fact be less inclined to walk due to complex household routines, especially for those with competing demands of childcare responsibilities, travel, time and work pressures (NICE 2012; Pooley et al. 2011). It is possible that people who have children may be particularly influenced by intersection density because route directness may have a substantial impact on the time it takes to reach destinations. Alternatively, people living in areas characterised by high intersection density may live in more urban areas in which car travel is less accessible.

People who did not have vehicle access also appear to be more affected by intersection density; they had increased probability of having completed a walk with increasing intersection density compared with people who had vehicle access. The results showing increased walking for people without vehicle access is in the intuitive direction, suggesting that for people who do not have the option of driving may be more likely to be encouraged to walk, particularly in neighbourhoods that have high intersection density. It is possible that people who rely on walking to carry out daily errands are particularly influenced the availability of direct routes, but further evidence is needed to support this hypothesis. However, there is no clear reason why people who don't have car access are less likely to do more walking overall. One possibility is that people who own a car are more likely to take part in longer recreational walks whereas people who do not have vehicle access make more short utilitarian trips as part of daily life. Alternatively, it is possible that this outcome is the result of residual confounding from factors not included in the analysis.

7.5 Sociospatial distribution of Area Walking Potential measures

This section discusses the results in relation to research aim:

To examine the pattern of geographic distribution of the four built environment measures across urban Scotland investigating area-level socio-spatial inequalities in access to the built environment by area characteristics.

7.5.1 Geographic distribution of Area Walking Potential measures

AWP was not distributed equally across urban Scotland, the levels of AWP that were captured by the measures were clustered in certain geographic regions of urban settlements. This showed that people living in areas with higher or lower AWP were more likely to live close to neighbourhoods with similar levels of AWP. The results of this study showed modest correlations between AWP and population density which echoes other literature (for example, Glazier et al. 2014) and so this may play a part in the unequal distribution of the measures across Scotland. Higher population density is associated with higher AWP because higher population densities can support such BE amenities such as more destinations.

Other studies have found similar clustering patterns and have used these to classify urban areas according to their geographic position and access to walking environments (King & Clarke, 2015; Riva, et al., 2009; Siu et al., 2012). For example, Siu et al. (2012) used cluster analysis to classify metropolitan areas of Portland, Oregon into central city, city periphery, suburb, urban fringe with poor commercial area access, urban fringe with poor park area access and satellite city. Riva et al. (2009) used measures of Active Living Potential (ALP) to classify areas of Montreal into Low-density suburban, Middle-density suburban, Suburban/urban axial, Mixed urban/suburban, Urban residential, Diverse central urban, Central urban with high accessibility with increasing ALP. This is likely to be because of the way in which urban areas develop, typically growing 'outwards' with shops and services located centrally. By contrast suburban areas were designed to provide housing, often for people who desired to be to live away from the city centre and closer to countryside (Whitehead 2008) with a focus on providing a spacious, quiet and safe environment rather than having high AWP. The impact on urban populations is that urban residents have geographically unequal access to environments that are considered to support walking. This may limit people's opportunities for neighbourhood walking which may impact on health behaviours such as total physical activity.

7.5.2 Distribution of Area Walking Potential by area deprivation and trends in walking by area and individual socioeconomic status

Significant relationships were found between area deprivation and AWP. People living in the least deprived strata had disproportionately lower AWP than people living in the higher three deprivation strata. This research provides the first national level evidence of the distribution of AWP in relation to area deprivation across all urban areas of Scotland and thus makes and important contribution to what is known about AWP and deprivation in Scotland. The findings of this research correspond with evidence from other studies in the UK and Scottish context finding increased access to walking and physical activity resources in more deprived areas, which has included access to greenspace (Jones et al. 2009), recreational PA facilities (Ogilvie et al. 2011; Lamb et al. 2012) and outdoor play areas for children (Ellaway et al. 2007), although one English study also found fewer PA resources in more deprived areas (Hillsdon et al. 2006). Another Scottish study compared walkability in areas around primary schools across urban Scotland finding significantly lower walkability in the least deprived areas (Macdonald et al. 2016). Limited evidence from elsewhere has found positive associations between AWP, for example, Pearce et al. (2007) examined access to community resources across New Zealand finding better access in more deprived urban areas than less deprived areas. However, evidence from outside the UK commonly shows the opposite trend with worse access to resources in more deprived areas than in less deprived areas, such as in the US (Estabrooks et al., 2003; Gordon-Larsen et al., 2006; Powell et al. 2006) and Australia (Turrell et al. 2013).

Such differences may be at least partly attributable to the historical development and design of urban spaces. Many UK urban areas evolved prior to the use of motorised vehicles and are typically higher density with greater concentration of housing, amenities and services (Giuliano & Narayan 2003). It was only in the past half century that there was an increased focus on investment in major urban road building and measures maximising vehicle capacity (Jones 2014) but more recently, there has been a resurgence of interest in supporting walking and cycling, and pedestrian accessibility is increasingly being given priority in urban design and planning policy (The Scottish Government 2010a; Jones 2014). In other places, such as the US, planning for vehicle capacity was often analogous with the development of urban settlements and occurred prior to the expansion of vehicle capacity in UK towns and cities (Jones 2014). Vehicle movement was given priority in a series of US transport planning policies since the post-war era. For example, the Federal-Aid Highway Acts of 1934, 1944 and 1956 prioritised funding for the development and proliferation of highways (Weiner 1992). The contrasting outcomes found in this study highlight the importance of context-specific research to ensure that policy development is based on appropriate local or national evidence rather than international findings. Theories and policies designed to improve neighbourhood conditions should take this type of context-specific contemporary evidence into account.

The findings show that people living in neighbourhoods with higher deprivation do not experience a double jeopardy of poor opportunities for walking. However, despite having AWP, this did not translate to higher walking outcomes for people in more deprived areas. Conversely, people living in more deprived areas were less likely to have done any walking or to have done multiple walks even after controlling for the influence of individual-level influences on behaviours. By contrast, AWP was lowest in the least deprived areas, yet walking outcomes were higher for people living in the lowest deprivation category compared with more deprived areas. This shows evidence of an 'area effect' of deprivation on walking, that deprivation is negatively associated with walking outcomes independently of AWP. The previous section on individual socioeconomic status also discussed findings of lower walking outcomes among people with lower levels of certain measures of individual SES. People with lower educational attainment, lower occupational grade or who were unemployed may be less likely to walk even in areas with high AWP.

The causal mechanisms underlying differences in PA outcomes for people living in areas with different levels of deprivation or different levels of SES are little understood. Areas Socioecological models can be used to help to identify pathways whereby intervening factors may modify the ways in which people perceive and interact with their environment, which can help to try to understand such differences. While resources may be physically present in more deprived neighbourhoods, the quality or attractiveness or safety may present barriers to their use. One of the core precepts of socioecological models, is that area or individual characteristics can influence the way in which people perceive and react to their environment (Shortt et al. 2014). . There is evidence that despite higher availability of resources in more deprived areas, negative perceptions of their quality, safety and aesthetic appeal can influence how readily these are used by residents which may lead to persistent inequalities between area deprivation and walking despite higher provision of amenities in these areas (Ellaway et al. 2007; Estabrooks et al. 2003; Jones et al. 2009; Mitchell & Popham 2007; Nagel et al.

2008). Jones et al. (2009), for example, found that respondents in more deprived areas of England lived closer to green spaces, but reported poorer perceived accessibility, poorer safety, and less frequent use. Ellaway et al. (2007) found that people in poorer areas of Glasgow are more likely to report a lack of safe places for children to play, despite higher frequency of play spaces in more deprived areas. A report for the Scottish Executive by Curtice et al. (2005) compared perceived incivilities for Scottish adults living in areas with different levels of deprivation across Perceived problems were higher across sixteen categories of incivilities in areas with high compared with low deprivation, including, 'availability of pleasant places to walk', which was considered a problem by 37 respondents in the highest deprivation area compared with none in the lowest deprivation neighbourhoods.

Relationships between accessibility and perceived attractiveness may be complex and contradictory. Adkins et al. (2012), for example found that AWP features that are beneficial to pedestrian navigation, such as cross roads, landscaped pavement buffers and setbacks were negatively associated with attractiveness. In making an area more physically accessible, it may reduce how attractive it is perceived to be. Whereas there may be attributes of less deprived areas that mitigate lower AWP such as social and aesthetic qualities so people may perceive them as more attractive making them more likely to walk in these neighbourhoods (Cerin et al., 2009; Freeman et al., 2013). Such differences in perceptions in high deprivation areas may mean that people are less likely to choose to take part in PA in these areas or to walk for leisure which may at least partly account for the lower walking outcomes in more deprived areas. The AWP measures created for this study focussed on functional and destination factors rather than aesthetic features. This may have overlooked the importance of perceptions of attractiveness.

Another facet of socioecological models is the role of cultural and institutional influences on behaviour. Institutional factors could influence propensity for walking for people living in more deprived areas such as longer working hours (Stokols 1996). Others have argued that lower PA is more common in people with lower SES because they are not buffered by protective factors such as better job opportunities and living conditions (Rind et al. 2014). Social cohesion, social norms and social capital may influence walking (Pan et al. 2009,Cerin et al. 2009). A recent cross-national study carried out as part of the SPOTLIGHT project found that objective environmental features only explained a small part of the variation in neighbourhood perceptions. Instead, the authors reported that lower levels of social cohesion was one of the more salient factors for differences in perceptions, reportedly explaining around 52% of differences in neighbourhood perceptions between residents of high and low deprivation neighbourhoods (Mackenbach et al. 2016). Other evidence has found an inverse correlation between social cohesion and area deprivation (McCulloch et al. 2012) and so it is possible that lower levels of social cohesion could play a part in the lower walking outcomes found in more deprived areas in this study.

It is also important to consider differences in types of walking. Socioecological models emphasise the importance of different contextual influences on different types of behaviour. There is considerable evidence in agreement with the results of this study, that people in areas with higher deprivation take part in less leisure or overall PA. In Scotland, people living in the most deprived areas are least likely to have met physical activity recommendations (Leadbetter et al. 2014; Munro et al. 2012) and less likely to walk for recreation (Munro et al. 2012). This outcome is echoed in a number of other studies including evidence from the UK (Stafford et al. 2007) Australia (Kavanagh et al. 2005; Giles-Corti 2002) and Brazil (Reis et al. 2013). However, there is evidence of greater utilitarian PA in more deprived areas. Higher area or physical deprivation was associated with increases in walking or active travel both in Scotland and the UK (Shortt et al. 2014; Stafford et al. 2007; The Scottish Government 2012) and beyond (Turrell et al. 2013; Giles-Corti 2002; Goodman 2013; Van Dyck et al. 2010; Pearce & Maddison 2011). The discrepancy between the results of this study with evidence of increased walking for transport in areas with higher deprivation may be because this study could not distinguish between transport and leisure walking, it is possible that people in more deprived areas take part in more walking for transport but less walking overall.

Additionally, people in more affluent areas may take part in more overall walking or PA because they access recreation facilities in a different way. In their study of sociospatial relationships between physical activity resources and behaviours in Scotland, Lamb et al. (2012) found that the most affluent neighbourhoods have poorer access to facilities that can be reached on foot, by bicycle or by bus than those living in less affluent areas. However, there were a greater number of facilities accessible by car. Thus, having access to a car may counteract the otherwise disadvantaged access experienced by people in these areas, particularly since car ownership is higher in more affluent neighbourhoods (The Scottish Government 2003b).

Notwithstanding these potential pathways for diminished walking outcomes in more deprived areas, a key outcome of this research was that there were no significant differences in the strength of associations between AWP and walking for people living in areas with different levels of deprivation. This is an important finding because it shows the potential of AWP to leverage walking in more deprived areas. Greater AWP could help reduce the area level inequalities in frequency of walking by facilitating more walking in areas with high deprivation. In this way, AWP could attenuate the negative effects of worse area deprivation and help to increase walking for people who are less likely to walk. The results of this study showed positive outcome for equity in access and distributional justice of AWP in urban Scotland since this distribution may limit wider disparities in neighbourhood inequalities in health (Pearce et al. 2007). This potential for environments to narrow health inequalities, is known as equigenesis (Mitchell et al. 2015; Pearce et al. 2010). By providing opportunities to support walking, the built environment can be an important mechanism through which opportunities for healthy behaviours are supported, potentially exerting an equigenic effect.

7.5 Summary

This study has demonstrated the importance of a context-specific approach to investigating associations between AWP and walking. Several of the results of this study have contrasted with findings in other countries or have generated fresh evidence in the urban Scottish context. These results have shown that environments considered to support walking are not equally distributed across Scotland. However, the findings highlight some potential for the built environment to support walking even after controlling for individual and area level confounders, showing the important role of the environment in shaping and facilitating behaviours. It is evident that relationships between the BE and walking are specific to BE measures and walking outcomes. This is an important finding for understanding how the BE can be used to support walking in Urban Scotland, which is explored in the following chapter. It is clear from the results of this study and others that such GIS measures of AWP do not determine behaviour, rather it offers potential to support choices about walking. The results of this study show that despite having equal access to features of the BE considered to support walking, there remain important differences in walking outcomes for different groups of people in different places. Educational attainment emerged as being associated with walking behaviour. As discussed in the beginning of this chapter it is possible that educational attainment reflects socioeconomic status, and a variety of reasons for differences in walking for low SES groups have been considered.

Social ecological models show that behaviours result from a complex interplay between people with their environments, operating at multiple levels of influence. Choices about health behaviours such as walking are constrained and facilitated not just by external influences but by this dynamic interplay between people and their environments which may be objective and subjective, institutional and cultural. This discussion has explored the ways in which using a socioecological approach can help to elucidate the pathways and processes that may contribute to these outcomes. The model used to guide this research is shown in Figure 19. This reflects a small part of the more comprehensive model of influences on walking behaviour in Figure 18. This model has been successful in developing this research project in that it showed how AWP in the form of BE measures are associated with walking outcomes, which is supported by the results of this research. It also showed pathways whereby other variables at different 'levels' such as individual level and area level factors educational factors might intervene in this pathway. The results of this research were congruent since some factors including individual educational attainment and area level deprivation displayed associations with people's walking behaviour independently of AWP. However, as discussed in Chapter 2, this model is deliberately simplified and takes only a small section of the influences on walking unlike the more comprehensive model shown in Figure 18. The model does not specify which variables for the BE measures or intermediary factors. It does not rank AWP and intervening measures in terms of association with walking, and thus implies that they are equal. The results of the empirical research revealed that this was not the case. For example, destination accessibility had stronger associations with walking than the other measures of AWP, and educational attainment was more closely associated with walking than other measures of SES. Alfonzo's 'hierarchy of walking needs' model shown in Figure 14 shows a hierarchy of influences on walking, showing factors such as 'pleasurability' as being more highly influential than functional measures. An improvement to the model used in this research would be to attempt to specify and rank the potential influences on walking, to show their relative importance to one another. Additionally, this model did not specify how different types of walking might be subject to different influences. The model by Giles Corti, et al. (2005) (Figure

12), for example, shows how different types of factors influence different types of walking for example, aesthetic features are shown as influencing leisure walking not transport walking. Had this research separated different walking types as outcomes of interest it might have been possible to make more specific connections about which types of influence are associated with different types of walking. This is discussed in more detail in section 8.4.3. Finally, this model does not specify what comprises people's 'neighbourhood', or acknowledge that this is likely to be different for different people. Such individualised and fluid neighbourhood activity spaces may mean that there is a mismatch between experienced or perceived neighbourhoods and buffer zones (Chaix et al. 2013). The following Chapter of this thesis will consider the implications of these findings in the international and Scottish policy context. It will summarise the main contributions and limitations of the research and identify future research directions.

Chapter 8. Conclusion

8.1 Introduction

The aims of this research were to examine the distribution of AWP across urban Scotland, and to test associations between neighbourhood AWP and residents' walking. The theoretical model used to guide the research is shown in Figure 18. This situates the potential influence of the built environment in the global, national and local context. which includes the policy context, shown part of the external social environment shown in Figure 18. The model indicates the potential of AWP in the form of the BE to influence and be influenced by policies. This chapter begins with a discussion of the implications of this research for international and Scottish policy. This is followed by a discussion of the key strengths and contributions of the research before discussing its limitations and future research directions.

8.2 The policy context and implications of the research findings

8.2.1 Introduction

Increasing physical activity is recognised as a global policy priority, particularly in the wake of rising overweight and obesity. There is increasing recognition of the importance of the built environment (BE) as a mechanism for increasing physical activity and walking outcomes in international and national policy. This study investigates associations between the built environment and walking in urban Scotland and so the results of this research can be considered in the context of current policies. The Department of Health 2009 report 'Be active, be healthy: a plan for getting the nation moving' highlighted the potential of local environments to have a direct influence upon levels of physical activity and to motivate recreational walking and cycling. The report points out the benefits of good urban design for offering safety and convenience for pedestrians (Department of Health 2009). Scotland has been proactive in promoting walking as a policy priority and in 2014 published a National Walking Strategy (The Scottish Government 2014). This document describes three key aims which are to:

1. Create a culture of walking where everyone walks more often as part of their everyday travel and for recreation and well-being

2. Better quality walking environments with attractive, well designed and managed built and natural spaces for everyone

3. Enable easy, convenient and safe independent mobility for everyone

(The Scottish Government 2014).

The Scottish Government's policy aims have embraced the potential of the BE to support active behaviour, particularly walking. Good Places, Better Health - the Scottish Government's 2008 strategy for health and the environment - recognises the need for greater insight into how physical environments influence health. More recently, the Scottish Government published their 'Designing Streets' policy document focussing on the creation of 'successful places through street design that promotes and prioritises pedestrian movement' (The Scottish Government 2010a). This Scottish policy agenda marks a departure from some strategies from the recent past which emphasised individual responsibility and choice rather than considering the enabling and constraining role of the environment in people's behavioural choices, for example, the UK Government's 2004 White Paper 'Choosing Health' (Department of Health 2004). This is summed up in the forward statement by the then Prime Minister Tony Blair who wrote:

For each of us, one of the most important things in life is our own and our family's health. I believe that this concern, and the responsibility that we each take for our own health, should be the basis for improving the health of everyone across the nation… We are clear that Government cannot - and should not - pretend it can 'make' the population healthy.

Tony Blair, 2004, p.4

By demonstrating the potential of key features of the built environment to influence walking the results of this research are highly relevant to and consistent with contemporary government policies. This is discussed in detail below.

8.2.2 Associations between the built environment and walking

This research showed some associations between AWP with walking, providing evidence of the potential of the BE to support walking in urban Scotland. In particular, there were strong associations between destination accessibility with walking. Therefore, this feature of the BE should be considered of key value for policy makers aiming to develop the BE to support walking, designing and planning communities with local infrastructure to support every day activity may help to augment walking behaviour. This is congruent with Scottish Government policy which advocates walkable access to local amenities (The Scottish Government 2010a). Associations between walkability and walking outcomes were weaker than for destination accessibility. The main outcome was that people living in neighbourhoods with highest walkability were more likely to have completed multiple walks and having achieved 30 minutes of walking by comparison with people living in neighbourhoods with the lowest walkability. This shows emerging evidence of the potential of a combined walkability metric to aid policy and planning, but implies the need for further investigation and refinement. Similarly, street permeability was only associated with increases in likelihood of having achieved 30 minutes walking for people living in neighbourhoods with the highest levels of street permeability compared with those living in the lowest. There were no associations with residential density and walking. Whilst increasing residential density and street connectivity has been advocated as a policy opportunity, especially in North America, in Scotland it is unlikely that this will substantially enhance walking behaviour. The reasons for these differences have been discussed in the previous chapter and include differences in the urban structure and historical development of urban spaces in different contexts.

There were key differences between different walking outcomes. Strongest associations were for the likelihood of having completed multiple walks. There were weaker associations for likelihood of having completed any walks or achieved 30 minutes walking. The differences between these outcomes may represent groups of people with distinct walking behaviours. It suggests that those who are inclined to walk are the most likely to be influenced to walk more by a supportive BE. However, people who are disinclined to walk at all appear to be much less influenced by the BE and may benefit from different or complementary strategies, such as individually targeted approaches to encouraging walking alongside enhancements to the BE. Policy makers should be mindful of such differences in outcomes when choosing strategies to leverage walking. One of the Scottish Government's policy aims is that interventions should be targeted at the most sedentary groups (The Scottish Government 2014); the evidence from this study suggests that people falling into this group may be less likely to change their behaviour based on improvements to the built environment alone, and may benefit from complementary initiatives discussed subsequently in this section. Policy makers should be mindful of differences in walking outcomes and consider whether policies to encourage walking are appropriate for the desired walking outcome to devise effective policies.

8.2.3 Sustainability agenda

Promoting walking in urban centres has also been championed as part of an increasingly imperative sustainability agenda and the need to reduce carbon emissions and promote sustainable travel (The Scottish Government 2013a; Department of Health 2009; WHO 2012). At a global level, the World Health Organization's (WHO) Sustainable Cities Agenda includes creating compact urban neighbourhoods served by transit and dedicated walking/cycling ways to promote active travel with attendant health benefits (WHO 2012). The UK Department of Health notes that a more active environment is a more sustainable one and that more cycling and walking as part of daily life can save money and help the environment. Fewer car journeys can reduce traffic, congestion and pollution, feeding back into the health of communities (Department of Health 2009). The Scottish Government's 'Creating Places' policy document states the aim of cutting carbon emissions by reducing reliance on cars through widening travel choices. Fundamental to this aim is the need to encourage more travel by foot and bicycle and a move away from the reliance on private cars (The Scottish Government 2013a). It is argued that the design of walkable neighbourhoods has the potential to reduce greenhouse gas emissions related to everyday journeys and that urban developments should be designed to accommodate a range of housing, local retail, leisure facilities, and high quality green spaces which are attractive, rich in biodiversity and well connected (The Scottish Government 2013a). The results of this research complement these aims, showing that BEs with high levels of destination accessibility and street connectivity can support increased walking and contribute towards sustainability agendas in Scotland and beyond. This research showed that people living in areas with higher intersection density were more likely to have completed a walk if they did not have a car than people who had car access. A potential policy implication could be discouraging car use alongside improvements to the BE may increase walking and reduce reliance on car travel. In general, policies directed at reducing energy consumption in the form of reduced reliance of vehicle transport should consider the potential of the BE to leverage walking trips.

8.2.4 Inequalities in walking environments and walking

Tackling health inequalities is a key policy priority. Geographical differences in exposure to health promoting environments is a potential driver of inequalities in health outcomes (Pearce et al. 2010) and equalising exposure to health-promoting environments has been identified as a policy objective in Scotland (The Scottish

Government 2008). Increasing physical activity and reducing sedentary behaviour is likely to form a part of any successful strategy since this may improve related health outcomes. AWP can be considered as one such health promoting environment and this study provides the first country-wide evidence that the distribution of AWP is unequal across urban Scotland, showing the potential for policy action in this area.

The results showed high AWP concentrated in certain geographic areas or urban settlements. Policy makers should be mindful of these inequalities when approaching urban development. Focussing on developing AWP in more peripheral parts of urban settlements would help to equalise accessibility by rejuvenating suburban regions to enhance walkability, creating community hubs in suburban areas rather than having a single centre surrounded by suburbs with few resources. These ambitions are also embedded in the Scottish Government's 'Placemaking' initiative which stipulates that successful places must be *distinctive, safe and pleasant, welcoming, adaptable, resource efficient and easy to move around and beyond* (The Scottish Government 2013b). This ambition is also reflected in the concept of new urbanism (compact, transit accessible, pedestrian-oriented, mixed use development within existing urban regions (Handy 2005)) and *'smart growth'* which includes creating suburban and rural communities with housing and transportation choices near jobs, shops and schools while supporting local economies and protecting the environment (Smart Growth America 2016). Developing more diverse environments within suburban areas could result in more people having access to AWP facilitating more equitable geographic distribution of AWP measures. The results of this study also showed differences in the distribution of the BE features, showing that residential density and destination accessibility were less equally dispersed than intersection density. This information can be used to guide interventions to target these features of the built environment to maximise equality of access to AWP.

The findings that particular geographic regions were associated with different AWP is also useful for policy makers wishing to identify target areas of greatest need to tackle spatial inequalities in access to AWP (Riva et al., 2009). Promoting low-cost physical activity such as walking is seen as one route to reducing health disparities by encouraging physical activity among groups that take part in less physical activity overall (King & Clarke 2015). The results of this research showed that people living in areas with worse deprivation walked less. However, positive associations between the BE and walking persisted even in areas with high deprivation. This is an important finding because it highlights the potential of the BE to support walking amongst people living in areas with high deprivation. However, broadly, areas with low AWP were also found to have low deprivation. Therefore, approaches to enhancing AWP that are country-wide or aim to target areas with the lowest AWP, run the risk of increasing health inequalities by enhancing environments among the least deprived sectors of the population at the expense of those in most deprived areas. The data generated through this analysis can be used to help identify areas where there is lowest AWP and high deprivation. This would enable policy makers to formulate geographically targeted interventions for people in places with the highest need. Improving AWP in areas of high deprivation may attenuate some of the negative effects of worse area deprivation and help increase walking for people who are less likely to walk. Such an approach could help to reduce area-level inequalities in participation in walking, acting as a mediator between area-level deprivation and walking outcomes.

The results of this study revealed certain groups for whom the built environment may be less successful in supporting walking. People with lower SES characteristics of lower educational attainment and lower employment status/grade walked less than those with higher SES even in areas with high AWP. The findings that there is frequently higher AWP in areas with high deprivation yet that people living in these areas frequently take part in lower SES could be misinterpreted by audiences such as policy makers and politicians to mean that the 'blame' for lower walking and physical activity lies with individuals living in these places. However, referring to socioecological modelling of behaviour and interpreting this outcome in the wider context shows a more complex picture. People who have lower SES may experience additional barriers such as lower self-efficacy or worse perceptions of their environment. Examples of such models are discussed in Chapter 2 such as those by Sallis et al. (2006) and Bauman et al. (2012). These show different levels of influences on behaviour including individual, social, cultural and perceived environments as well as wider external influences such as environmental and global influences. The Scottish Government's strategy document on health and the environment uses the DPSEEA (Drivers, Pressures, States, Exposures, Effects, Actions) model of health to show a system of different types of social, economic and political drivers which modify the environmental state which influences exposures and effects on human health (Donnelley 2008). Policies may have greater chance of success at promoting walking among the groups identified by this research as being less likely to increase walking in areas of high AWP if they embrace strategies that operate at such multiple levels of influence. These may include educational and behavioural interventions and individual-focused interventions in more walkable neighbourhoods that encourage people to use those resources. Developing multilevel strategies that support the different needs of individuals is likely to involve interdisciplinary working across institutions and organisations. Pearce and Maddison (2011) note that addressing issues relating to the built environment will require interdisciplinary collaboration, for example across planning and urban design, architects, sports and recreation and transportation as well as the public health community. Such approaches are more likely to meet policy ambitions for tackling inequalities by accounting for the needs of specific groups. For example, the Scottish government's National Walking Strategy ambition that interventions should be tailored to individual people's needs (The Scottish Government 2014) as well as collaborative projects across disciplines and sectors involving local groups and activities (The Scottish Government 2013a).

8.2.5 Summary – the policy context

This research has demonstrated the importance of the built environment for supporting walking and has generated policy-relevant evidence that is applicable to national and international policies aimed at supporting physical activity and tackling health inequalities. The model used to guide this research included the potential of global, national and local contexts to influence and be influenced by AWP in the form of the built environment, reflecting the potential of this research to generate policy relevant evidence at these levels, although the it did not show the specific pathways through which this could occur. This discussion has elucidated how the results of this research are likely to be of interest to policy makers of the fields of health, planning and sustainability. This study has also generated evidence that is directly relevant to agendas aimed at tackling inequalities, showing how both area and individual level deprivation are likely to affect the success or relevance of policies. The results show a need for more nuanced approach to policy making that is sensitive to the structure of cities, degree of inequalities and recognises articular histories and trajectories in urban development.

8.3. Key strengths and contributions of this research

This research has generated evidence about associations between the built environment and walking in the Scottish context. Research of this type has been carried out in other places, particularly in the US and Australasia, but this type of research is less common in the European context and rare in the UK Scottish context. This research makes a novel contribution to the international literature by providing evidence from a country with a different urban infrastructure than from North America and Australasia. Within the international literature, associations between certain measures of the BE and walking, such as street connectivity and residential density, have become increasingly accepted. Such measures are frequently re-used. They have been applied in studies in a range of countries including New Zealand (Maddison et al. 2009), the US (Frank et al. 2010; Freeman et al. 2013), Canada (McCormack et al. 2012; Thielman et al. 2015), Sweden (Sundquist et al. 2011) and Belgium (Van Dyck, Cardon, Deforche, Owen, et al. 2011), are recommended for use in international projects for example by IPEN (International Physical Activity and the Environment Network) (IPEN 2016) and used in international tools such as walkscore.com®. This study found that such features were not strongly associated with walking in the Scottish context. This makes an important contribution to the international literature, highlighting the importance of context specific research.

The study's focus on contemporary policy challenges of physical activity and health inequalities makes it relevant to the national and international policy context. This study is unusual in that it generated evidence based on data from urban areas across a whole country, rather from a case study based on a small area, this means that the findings can be considered applicable across urban Scotland.

Testing associations between four built environment measures meant that comparisons could be made between the strength of associations between these different measures and conclusions drawn about the relative strength of their associations with walking. This study makes a unique contribution to the literature on walkability. It is one of few walkability studies that considers whether each of the component measures of walkability have associations with walking as well as the composite measure and it is important to unpack the relative influence of BE measures on PA as well as to understand the composite influence. Macintyre et al. (2002) have commented that area effects are often a 'black box' of somewhat mystical influences on health and they and others have suggested that the analysis of specific local, social and physical environmental domains should be considered in the place of global summary measures (Stafford et al., 2007). By comparing each of the component walkability measures as well as the combined measure this study tests the independent contribution of each measure and compares this with the synergistic influence of the composite measure. In so doing, this study has challenged what is frequently an uncontested acceptance of walkability metrics, which are developed and applied without theoretical or empirical interrogation (Van Dyck et al., 2010).

Sensitivity testing was carried out to compare associations between AWP and walking for different neighbourhood sizes and different types of walking. Neighbourhoods were created based on hypothesised walking distances from homes in two size zones to ascertain which of these was the most appropriate for investigating associations between AWP and walking. This is important because there is uncertainty about what constitutes people's typical neighbourhood walking area. This study augments the evidence base regarding the use of different neighbourhood size zones showing stronger results found using the larger zone. It also allowed a comparison of whether different sociodemographic groups included in this study had different relationships between BE measures and walking in these two zones.

This research considered four different walking outcomes which were deliberately selected to reflect different types of walking behaviour. This is important for understanding nuances and differences in associations between AWP with different types of walking outcomes. The results showed key differences in outcomes which contributes to understandings of associations between AWP and specific walking behaviours.

The consideration of inequalities was incorporated into this research design, providing new evidence in this area. This research identified geographic areas with high and low AWP, providing new and unique insight into this type of data in the Scottish context. This research included the consideration of health inequalities in relationships between the built environment and walking, which is frequently identified as an under-researched area and a research and policy priority. Firstly, by investigating and identifying differences in walking behaviour in relation to the built environment, and secondly considering inequalities in associations between the built environment and walking. The results show how different groups and people in areas with different levels of deprivation interact with their environment differently. This is an important outcome for understanding how the built environment can be used to successfully support walking across the population. It shows that policies aiming to increase walking across the population should be mindful of these differences and that multilevel interventions involving inter-agency working are likely to be the most successful.

Using a socioecological model to guide the analysis and interpretation of this work facilitated an understanding of the complexity and multi-layered interactions between people and their built environments. This model includes the importance of physical surroundings such as built environments for influencing behaviour. However, the model also draws attention to other types of influence operating at different 'levels' such as interpersonal, subjective and individual level factors. The model incorporates an understanding of the interactions between people and their environments. This guided the consideration of inequalities in relationships between the built environment and walking, embracing a holistic understanding of the synergy between people and the places in which they act.

8.4 Limitations of the research

The limitations of this research are summarised below.

8.4.1 Study design

This study used a cross sectional research design which was necessary because it used secondary data from the Scottish Health Survey. This meant it did not account for 'self-selection', in that individuals who prefer to carry out more physical activity may be more inclined to select areas with facilities for walking, resulting in a failure to account for self-selection bias in the outcomes (Owen et al., 2007). This means it is not possible to determine the true direction of the positive associations found, that is, to know whether people living in areas with higher AWP are inclined to do more walking, or whether people who prefer to do more walking chose to live in areas with high levels of the built environment measures to support this preference. However, the positive associations found in this research are congruent with national and international evidence based on diverse research designs and settings, which included some with longitudinal (Knuiman et al. 2014; Wells & Yang 2008) and experimental study designs (NICE 2006b; NICE 2006a) or included area preference as a covariate in the research (Witten et al. 2012). The large sample size used in this research will also help to mitigate the potential for self-selection bias because it is more likely to capture diverse motivations for walking.

8.4.2 Neighbourhood definition

In this study neighbourhoods were defined using two fixed geographic units. However, definitions of neighbourhood are contested. Individuals' perceptions of what constitutes their neighbourhood are subjectively defined rather than representing a fixed geographic area. Thus, residents perceive the boundaries of what constitutes their 'neighbourhood' differently from one another. A paper by Ivory et al. (2015) found people made their own activity spaces depending on the availability of local resources. For example, people would make more distant places 'near' when living in areas with lower physical activity resources. What constitutes 'neighbourhood may also vary, for example, according to their life stage, their usual means of transport, mobility restrictions or individual idiosyncrasy (Stafford et al., 2007). This is captured by the concept of individualised activity spaces which is used to describe individual movement patterns such as travel origins, destinations and paths in between (van Heeswijck et al. 2015). As such it is unlikely that any fixed measure of neighbourhood is equally appropriate and meaningful for all participants and two size zones are unlikely to encompass enough diversity to capture 'neighbourhood' for all the people in the research. However, as discussed in Chapter 4, this researched was designed to explore the potential impact of AWP in proximate residential neighbourhoods so neighbourhood buffer zones were considered appropriate.

8.4.3 Walking data

Walking data were collected from the 2010 Scottish Health Survey which is a large national representative survey. A limitation of using secondary data sources is that it is not possible to influence the data collected. These data did not reflect people's motivation for walking, in terms of whether it was for recreation or transport. Other studies have shown this to be an important distinction and there may be clear differences in the influences on these different types of walking. As discussed in the previous chapter, had the data distinguished between different types of walking motivation, different associations may have been found.

The survey did not ask respondents about the location of their walking which may not have occurred within the designated neighbourhood zones. As the data do not show where people walked this could have weakened the results by failing to reflect neighbourhood walking as opposed to any walking. For example, the finding that people living in more affluent areas do more walking, despite lower levels of the BE measures, may be because people who live in more affluent areas walk more outside their neighbourhood.

Walking was the only form of physical activity considered in this study for the reasons outlined in the beginning of this thesis regarding the importance and accessibility of walking. However, Andrews et al. (2012) observe that people 'run, cycle, skate, ski, dance, swim, row, skateboard, scoot, play, wheelchair' in urban spaces (Andrews et al. 2012, p. 1929) and these authors criticise health geographers for restricting research into understandings of other forms of physical activity. However, relationships between contexts and behaviours is behaviour specific, and so research into relationships between neighbourhoods and walking should address built environment features that are likely to influence walking (Giles-Corti, Timperio, et al. 2005) and the most appropriate geographic exposure scale is also specific to the behaviour in question (Ogilvie et al. 2011).

8.4.4 Measurement limitations

This study used secondary data sources for both the creation of data in GIS measures of AWP and the Scottish Health Survey (SHeS) for the walking data. It is possible that errors existed in the datasets for example the SHeS relied on respondent recall regarding their walking behaviour in the past four weeks so it is possible that this was subject to recall bias. The secondary data sources used to create the neighbourhood study site zones and the four built environment measures and area deprivation were checked for errors and every attempt was made to ensure the accuracy and completeness of the data.

8.4.5 Additional influences on walking

There are two possible sources of additional influences on walking. Firstly, there is potential for residual confounding including other features of the built environment such as topography (Rodríguez et al. 2008) and pollution could influence walking behaviours. Secondly, the study restricted AWP measures to objective features of the BE. There may be wider and multiple factors exerting simultaneous and interacting influences on behaviours such as walking. These may include aspects of the wider social environment such as local health promotion campaigns, perceptions of safety and quality and psychological factors such as self-efficacy (Panter and Jones, 2010).

8.5 Future research directions

8.5.1 Study design

Future research could use other research designs to overcome self-selection bias for example, by using experimental studies. These can include, for example, intervention studies whereby walking behaviour is measured before and after a new neighbourhood feature is introduced. Longitudinal designs that follow respondents throughout the lifecourse and measure associations between AWP with walking in different contexts, or studies that include neighbourhood preference as a covariate can also help overcome such bias.

8.5.2 Neighbourhood activity spaces

There is uncertainty regarding the most appropriate measure of neighbourhood geography. Stafford et al. (2007) note that this variability is an ongoing challenge for health studies of the residential environment. Curtis (2004) notes that geography places an emphasis on this difference between place and space, where space is defined by fixed boundaries and place is subjectively defined. Such a perspective suggests that sense of place, such as what constitutes 'neighbourhood' might be better investigated through qualitative work, which may then be applied to quantitative studies. Further evidence should be gathered before conclusions can be drawn regarding the suitability of different scales to establish the most appropriate neighbourhood exposure scale for understanding links between various built environment measures and walking in different contexts (Kwan 2012; Diez Roux & Mair 2010; Riva et al. 2009; Brownson et al. 2009; Nagel et al. 2008). This supports the value of using GIS to characterise different local neighbourhood zones in future studies for testing differences in walking outcomes using different activity spaces (Nagel et al. 2008).

8.5.3 Walking outcomes

Future research should continue to investigate the potentially important differences in influences on walking for transport and for leisure. This would in turn provide better information for how improving walkability may facilitate increased neighbourhood walking. This is important for policies advocating an active travel approach to reaching physical activity goals, which aim to support travel and transport by physically active modes as opposed to motorised ones (Cycling Scotland et al. 2012). Promoting active travel in particular is increasingly recognised as a public health priority in Scotland, the UK and beyond (Department of Health 2010; NICE 2006b; Das & Horton 2012; Donnelley 2008; Marmot 2010; Cavill & Rutter 2013), and is considered an achievable and effective way of increasing physical activity in the population. Further consideration of different types of walking outcomes may reveal strong associations between walkability and walking for transport, which can then be applied to policies aimed at increasing population-level physical activity through active travel or transport walking. Such policies may be particularly effective in contexts where people are less likely to walk for leisure, such as in areas with higher deprivation. This in turn could help to reduce area-level socioeconomic inequalities in walking outcomes through increasing walking in areas where people are the least likely to walk.

Four different walking outcomes were considered in this research, and each showed different relationships with built environment measures. However, comparing multiple walking outcomes is not common within the literature. Future research should also consider multiple walking outcomes in relation to built environments which may provide further evidence about what types of walking behaviour are most closely associated with built environment measures and reduce the potential for overlooking relationships with different types of walking outcomes. Greater theoretical and empirical specificity about different types of walking behaviour, differentiating leisure and travel walking will help to clarify relations. The consideration of additional movement behaviours such as cycling and skating was beyond the scope of this study but is a potential avenue for future research. Finally, the limited associations for people walking for 30 minutes or more may be because people who take longer walks do so outside of their neighbourhood, making associations with neighbourhood measures weak (Learnihan et al. 2011). Future research could record location of walking, for example by using GPS (for example, Rundle et al. 2015) to match walking behaviour with features of the activity spaces in which it takes place.

8.5.4 Measures of the built environment

Additional neighbourhood measures could be investigated to determine whether these contribute to associations between neighbourhoods and walking. Future studies that include improved objective and perceived measures of the built environment can strengthen evidence of causality through better research designs (Ding & Gebel 2012). Qualitative measures may augment what is known about associations between AWP and walking. Pak and Verbeke (2013) and Reid (2008) have argued that objective GIS measures of built environments are insufficient to reflect the complexity of AWP and suggest subjective and aesthetic measures are essential features of AWP. Collecting subjective qualitative data in large-scale replicable studies can pose a challenge as it is less inherently 'measurable' than objective features (Reid, 2008), but one that should be embraced and explored to get to the crux of what factors are likely to encourage walking. Innovative research design and the use of newer technologies may facilitate more subjective measures within quantitative research designs. Reid et al. (2008), for example, suggest incorporating the use of mobile technologies to facilitate more subjective evaluations.

Brownson et al. (2009) argue that in future research it is important to include factors from multiple levels of ecologic models which are likely to be more powerful in explaining behaviour. Such factors could include socio-political variables (Brownson et al., 2009), and personal efficacy relating to behavioural and health change (Stafford et al., 2007). Brownson et al. (2009) note that cross-disciplinary collaboration in fields such as environmental psychology may have the potential to develop such measures for the application to built environment measures.

8.5.5 Inequalities

There have been calls for more evidence into health inequalities (Petticrew et al. 2004). Although current policies have embraced the notion that behaviours are influenced and constrained by factors such as the built environment, there is still little recognition or practical implementation of strategies to address individual differences in walking behaviour. Individual-level variables are often used as controls or confounders but it is recommended that greater emphasis should be placed on understanding how such variables are likely to influence relationships, rather than controlling for their influence (Macintyre et al. 2002) and future research should include models that account for interactions between environmental influences and individual characteristics (Saelens & Handy 2008; Sallis et al. 2008; Owen et al. 2007). This will help to develop greater insight into inequalities in relationships between built environments and walking behaviours. In addition, people living in disadvantaged neighbourhoods may benefit from particular types of built environments, for example, health and recreational resources, jobs, and civic opportunities easy to access by walking (King & Clarke 2015). Further investigation into geographic distribution and accessibility of BE measures that are likely to support key population groups would show whether built environments have the capacity to support the needs of residents.

8.5.6 Policy relevance

This research aimed to provide policy-relevant evidence relating to the built environment, walking and inequalities in urban Scotland. Authors have argued that policy researchers need to be 'noisy' and make the case for the benefits of interventions, stipulating how research results such as these can be incorporated into policy to deliver tangible public health benefits (Lang & Rayner 2012; Petticrew et al. 2004). Future work could generate further policy relevance by investigating associations between built environments, walking and physical activity related health outcomes. This can be translated into a quantifiable assessment of the effectiveness and cost-effectiveness of improvements to the built environment. Evidence of this type has been identified as of key importance for policy makers wishing to use evidence-based research in policy interventions (Petticrew et al. 2004). Further testing and refinement of associations between the built environment and walking in urban Scotland will generate a stronger evidence base for associations that are of direct relevance in the Scottish context.

8.6 Concluding statement

This study has contributed to understanding associations between AWP and walking in the urban Scottish context. It has contributed to the national and international literature by identifying key features of the built environment that are associated with walking behaviours. It has also shown differences in findings in this Scottish context from based on evidence from overseas. This research has made a unique contribution to what is known about the distribution of Area Walking Potential (AWP) measures, identifying areas of high and low AWP across urban Scotland.

Tackling physical inactivity and related health inequalities is a national and international policy concern so evidence from this research is relevant to such policy agendas. The increasing disparities in health behaviours and health outcomes makes meeting these challenges imperative. Policy agendas now need to look to delivering tangible changes to neighbourhoods that facilitate walking and ensuring that access to such is geographically equal. Geographically targeted and multilevel strategies are likely to support walking for diverse groups of people and those living in areas where there is most need for support to achieve increases in physical activity.

Bibliography

Alfonzo, M.A., 2005. To walk or not to walk? The hierarchy of walking needs. *Environment and Behavior*, 37(6), pp.808–836.

Allison, P., 1999. Multiple Regression: A Primer.

Andrews, G.J. et al., 2012. Moving beyond walkability: On the potential of health geography. *Social Science & Medicine*, 75(11), pp.1925–1932.

Arvidsson, D. et al., 2012. Physical Activity and Concordance between Objective and Perceived Walkability. *Medicine and Science in Sports and Exercise*, 44(2), pp.280–287.

Badland, H. & Schofield, G., 2005. Transport, urban design, and physical activity: an evidence-based update. *Transportation Research Part D-Transport and Environment*, 10(3), pp.177–196.

Badland, H.M. et al., 2010. Examining Public Open Spaces by Neighborhood-Level Walkability and Deprivation. *Journal of Physical Activity & Health*, 7(6), pp.818–824.

Badland, H.M., Schofield, G.M. & Garrett, N., 2008. Travel behavior and objectively measured urban design variables: Associations for adults traveling to work. *Health and Place*, 14(1), pp.85–95.

Bailey, N., Bramley, G. & Gannon, M., 2016. *Poverty and social exclusion in urban and rural areas of Scotland Poverty and Social Exclusion UK Survey 2012 Working Paper*,

Ball, K. et al., 2007. Personal, social and environmental determinants of educational inequalities in walking: a multilevel study. *Journal of Epidemiology and Community Health*, 61(2), pp.108–114.

Ball, K. et al., 2012. Street connectivity and obesity in Glasgow, Scotland: Impact of age, sex and socioeconomic position. *Health & Place*, 18(6), pp.1307–1313.

Bauman, A.E. et al., 2012. Correlates of physical activity: why are some people physically active and others not? *Lancet*, 380(9838), pp.258–271.

Bauman, A.E. & Bull, F.C., 2007. *Environmental Correlates of Physical Activity And Walking in Adults and Children: A Review of Reviews*, National institute for Health and Clinical Excellence.

Berke, E.M. et al., 2007. Association of the built environment with physical activity and obesity in older persons. *American Journal of Public Health*, 97(3), pp.486–492.

Boone-Heinonen, J. et al., 2010. Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. *Int J Behav Nutr Phys Act*, 7, p.70.

Bopp, M. et al., 2006. Factors associated with physical activity among African-American men and women. *Am J Prev Med*, 30(4), pp.340–346.

Bracy, N.L. et al., 2014. Is the relationship between the built environment and physical activity moderated by perceptions of crime and safety? *International Journal of Behavioral Nutrition and Physical Activity*, 11.

Bradshaw, C., 1993. Creating – and Using – a Rating System for Neighbourhood

Walkability: Towards an Agenda for "Local Heroes." *International Pedestrian Conference*.

Bromley, C. et al., 2011. The Scottish Health Survey. , 1, pp.1–256.

Brown, L. et al., 2014. *The Scottish Health Survey 2014: Volume 1: Main Report*, Edinburgh.

Brownson, R.C. et al., 2009. Measuring the Built Environment for Physical Activity State of the Science. *American Journal of Preventive Medicine*, 36(4), pp.S99–S123.

Burton, N.W. et al., 2005. The relative contributions of psychological, social, and environmental variables to explain participation in walking, moderate-, and vigorous-intensity leisure-time physical activity. *Journal of Physical Activity and Health*, 2, pp.181–196.

Cain, K.L. et al., 2014. Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). *Soc Sci Med*, 116, pp.82–92.

Cao, X.Y., Handy, S.L. & Mokhtarian, P.L., 2006. The influences of the built environment and residential self-selection on pedestrian behavior: Evidence from Austin, TX. *Transportation*, 33(1), pp.1–20.

Carr, L.J., Dunsiger, S.I. & Marcus, B.H., 2010. Walk Score (TM) As a Global Estimate of Neighborhood Walkability. *American Journal of Preventive Medicine*, 39(5), pp.460–463.

Casagrande, S.S. et al., 2009. Built Environment and Health Behaviors Among African Americans A Systematic Review. *American Journal of Preventive Medicine*, 36(2), pp.174–181.

Cavill, N. & Rutter, H., 2013. Obesity and the environment: increasing physical activity and active travel .

CDC, 2010. US Center for Disease Control and Prevention, Racial & Ethnic Minority Populations.

Cerin, E. et al., 2007. Applying GIS in Physical Activity Research: Community "Walkability" and Walking Behaviors. In P. Lai & A. H. Mak, eds. *GIS for Health and the Environment*. Lecture Notes in Geoinformation and Cartography. Springer Berlin Heidelberg, pp. 72–89.

Cerin, E. et al., 2007. Destinations that matter: associations with walking for transport. *Health Place*, 13, pp.713–724.

Cerin, E., Leslie, E. & Owen, N., 2009. Explaining socio-economic status differences in walking for transport: An ecological analysis of individual, social and environmental factors. *Social Science & Medicine*, 68(6), pp.1013–1020.

Cerin, M. et al., 2013. Effects of built environment on walking among Hong Kong older adults. *Hong Kong medical journal = Xianggang yi xue za zhi / Hong Kong Academy of Medicine*, 19 Suppl 4, pp.39–41.

Cervero, R. et al., 2009. Influences of Built Environments on Walking and Cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, 3(4), pp.203–226.

Chaix, B. et al., 2013. GPS tracking in neighborhood and health studies: A step forward for environmental exposure assessment, a step backward for causal inference? *Health & Place*, 21, pp.46–51.

Clark, A.F., Scott, D.M. & Yiannakoulias, N., 2014. Examining the relationship between active travel, weather, and the built environment: a multilevel approach using a GPS-enhanced dataset. *Transportation*, 41(2), pp.325–338.

Clifton, K.J., Livi Smith, A.D. & Rodriguez, D., 2007. The development and testing of an audit for the pedestrian environment. *Landscape and Urban Planning*, 80(1–2), pp.95–110.

Cowie, C.T. et al., 2016. Neighbourhood walkability, road density and socio-economic status in Sydney, Australia. *Environmental Health*, 15.

Cumming, G.S., Cumming, D.H.M. & Redman, C.L., 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. *Ecology and Society*, 11(1)(14).

Cummins, S. et al., 2007. Understanding and representing "place" in health research: A relational approach. *Social Science & Medicine*, 65(9), pp.1825–1838.

Curtice, J. et al., 2005. *Public attitudes and environmental justice in Scotland*, Edinburgh.

Cutts, B.B. et al., 2009. City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access. *Social Science & Medicine*, 69(9), pp.1314–1322.

Cycling Scotland et al., 2012. "Active travel, active Scotland."

D'Haese, S. et al., 2014. The association between objective walkability, neighborhood socio-economic status, and physical activity in Belgian children. *International Journal of Behavioral Nutrition and Physical Activity*, 11.

Das, P. & Horton, R., 2012. Rethinking our approach to physical activity. *Lancet*, 380(9838), pp.189–190.

Day, R., 2008. Local environments and older people's health: Dimensions from a comparative qualitative study in Scotland. *Health & Place*, 14(2), pp.299–312.

Department of Health, 2009. Be active, be healthy: a plan for getting the nation moving. , pp.1–75.

Department of Health, 2004. *Choosing Health: Making Healthy Choices Easier*, London.

Department of Health, 2010. Healthy Lives Healthy People.

Diez Roux, A. V et al., 2007. Availability of recreational resources and physical activity in adults. *American journal of public health*, 97(3), pp.493–9.

Diez Roux, A. V & Mair, C., 2010. Neighborhoods and health. *Annals of the New York Academy of Sciences*, 1186, pp.125–145.

Ding, D. & Gebel, K., 2012. Built environment, physical activity, and obesity: What have we learned from reviewing the literature? *Health & Place*, 18(1), pp.100–105.

Donnelley, R.R., 2008. *Good places, Better health. A new approach to environment and health in Scotland implementation plan*, Edinburgh: The Scottish Government.

Duncan, M.J., Spence, J.C. & Mummery, W.K., 2005. Perceived environment and physical activity: a meta-analysis of selected environmental characteristics. *The international journal of behavioral nutrition and physical activity*, 2, p.11.

Dunn, A.L., Andersen, R.E. & Jakicic, J.M., 1998. Lifestyle physical activity interventions. History, short- and long-term effects, and recommendations. *American journal of preventive medicine*, 15(4), pp.398–412.

Van Dyck, D., Cardon, G., Deforche, B., Giles-Corti, B., et al., 2011. Environmental and psychosocial correlates of accelerometer-assessed and self-reported physical activity. *Int J Behav Med*, 18.

Van Dyck, D. et al., 2010. Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Prev Med*, 50, pp.S74–S79.

Van Dyck, D., Cardon, G., Deforche, B., Owen, N., et al., 2011. Relationships between neighborhood walkability and adults' physical activity: How important is residential self-selection? *Health & Place*, 17(4), pp.1011–1014.

Ellaway, A. et al., 2014. *Context Briefing 3 Changes over time in the provision of amenities and facilities*,

Ellaway, A. et al., 2007. Nowhere to play? The relationship between the location of outdoor play areas and deprivation in Glasgow. *Health & place*, 13(2), pp.557–561.

Ellaway, A. & Macintyre, S., 2001. Women in their place: gender and perceptions of neighbourhoods and health in the West of Scotland. In I. Dyck, N. Davis-Lewis, & S. McLafferty, eds. *Geographies of women's health*. London: Routledge, pp. 265–281.

Ellaway, A., Macintyre, S. & Bonnefoy, X., 2005. Graffiti, greenery, and obesity in adults: secondary analysis of European cross sectional survey. *British Medical Journal*, 331(7517), pp.611–612.

Equality and Human Rights Commission, 2015. Women, men and part-time work. Available at: http://www.equalityhumanrights.com/about-us/devolved-authorities/commission-scotland/legal-work-scotland/articles/women-men-and-part-time-work [Accessed April 12, 2016].

Eriksson, U., 2013. *Neighborhood environment and physical activity*. Lund University.

Eriksson, U. et al., 2012. Walkability parameters, active transportation and objective physical activity: moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, 9.

Estabrooks, P.A., Lee, R.E. & Gyurcsik, N.C., 2003. Resources for physical activity participation: does availability and accessibility differ by neighborhood socioeconomic status? *Annals of Behavioral Medicine*, 25(2), pp.100–104.

Evenson, K., Herring, A. & Huston, S., 2005. Evaluating change in physical activity with the building of a multi-use trail. *Am J Prev Med*, 28, pp.177–185.

Ewing, R. & Handy, S., 2009. Measuring the Unmeasurable: Urban Design Qualities Related to Walkability. *Journal of Urban Design*, 14(1), pp.65–84.

Fan, J.X., Wen, M. & Kowaleski-Jones, L., 2014. An ecological analysis of environmental correlates of active commuting in urban U.S. *Health & place*, 30, pp.242–50.

Fielding, J.L. & Gilbert, N.G., 2000. Understanding Social Statistics.

Filion, P., McSpurren, K. & Appleby, B., 2006. Wasted density? The impact of Toronto?s residential-density-distribution policies on public-transit use and walking. *Environment and Planning A*, 38(7), pp.1367–1392.

Flowerdew, R. & Martin, D., 2005. Methods in Human Geography.

Forsyth, A. et al., 2007. Does residential density increase walking and other physical activity? *Urban Studies*, 44(4), pp.679–697.

Forsyth, A., 2010. NEAT-GIS Neighborhood Environment for Active Transport-Geographic Information Systems.

Forsyth, A. et al., 2009. The built environment, walking, and physical activity: Is the environment more important to some people than others? *Transportation Research Part D-Transport and Environment*, 14(1), pp.42–49.

Foster, S. & Giles-Corti, B., 2008. The built environment, neighborhood crime and constrained physical activity: An exploration of inconsistent findings. *Preventive Medicine*, 47(3), pp.241–251.

Frank, L.D. et al., 2005. Linking objectively measured physical activity with objectively measured urban form - Findings from SMARTRAQ. *Am J Prev Med*, 28, pp.117–125.

Frank, L.D. et al., 2010. The development of a walkability index: application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine*, 44(13), pp.924–933.

Freeman, L. et al., 2013. Neighborhood Walkability and Active Travel (Walking and Cycling) in New York City. *Journal of Urban Health-Bulletin of the New York Academy of Medicine*, 90(4), pp.575–585.

Gebel, K. et al., 2011. Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain. *Health & Place*, 17(2), pp.519–524.

Gebel, K., Bauman, A. & Owen, N., 2009. Correlates of non-concordance between perceived and objective measures of walkability. *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine*, 37(2), pp.228–38.

Geddes, I. & Vaughan, L., 2014. *Why do people walk in the suburbs? An analysis of how spatial configuration and land use diversity contribute to walkability*,

Giles-Corti, B., Broomhall, M.H., et al., 2005. Increasing walking - How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine*, 28(2), pp.169–176.

Giles-Corti, B., 2002. Socioeconomic Status Differences in Recreational Physical Activity Levels and Real and Perceived Access to a Supportive Physical Environment. *Preventive Medicine*, 35(6), pp.601–611.

Giles-Corti, B., Timperio, A., et al., 2005. Understanding physical activity environmental correlates: Increased specificity for ecological models. *Exercise and Sport Sciences Reviews*, 33(4), pp.175–181.

Giles-Corti, B. & Donovan, R.J., 2002. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med*, 54(12), pp.1793–1812.

Giuliano, G. & Narayan, D., 2003. Another look at travel patterns and urban form: The US and Great Britain. *Urban Studies*, 40(11), pp.2295–2312.

Glazier, R.H. et al., 2014. Density, Destinations or Both? A Comparison of Measures of Walkability in Relation to Transportation Behaviors, Obesity and Diabetes in Toronto, Canada R. F. P. Bacurau, ed. *Plos One*, 9(1), p.e85295.

Glazier, R.H. et al., 2014. Density, Destinations or Both? A Comparison of Measures of Walkability in Relation to Transportation Behaviors, Obesity and Diabetes in Toronto, Canada (vol 9, e85295, 2014). *Plos One*, 9(3).

Goodman, A., 2013. Walking, cycling and driving to work in the English and Welsh 2011 census: trends, socio-economic patterning and relevance to travel behaviour in general. *PloS one*, 8(8), p.e71790.

Gordon-Larsen, P. et al., 2006. Inequality in the built environment underlies key health disparities in physical activity and obesity. *Pediatrics*, 117(2), pp.417–424.

Gordon, P.M., Zizzi, S.J. & Pauline, J., 2004. Use of a community trail among new and habitual exercisers: a preliminary assessment. *Preventing chronic disease*, 1(4), p.A11.

Grasser, G. et al., 2013. Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review. *International Journal of Public Health*, 58(4), pp.615–625.

Greenspace Scotland, 2011. Greenspace Map. Available at: http://greenspacescotland.org.uk/scotlands-greenspace-map.aspx.

GreenspaceScotland, 2009. *State of Scotland's Greenspace 2009*,

Hambling, T., Weinstein, P. & Slaney, D., 2011. A Review of Frameworks for Developing Environmental Health Indicators for Climate Change and Health. *International Journal of Environmental Research and Public Health*, 8(7), pp.2854–2875.

Handy, S., 2005. SMART GROWTH AND THE TRANSPORTATION–LAND USE CONNECTION: WHAT DOES THE RESEARCH TELL US? *International Regional Science Review*, 28(2), pp.146–167.

Handy, S.L. et al., 2002. How the built environment affects physical activity - Views from urban planning. *American Journal of Preventive Medicine*, 23(2), pp.64–73.

van Heeswijck, T. et al., 2015. Differences in associations between active transportation and built environmental exposures when expressed using different components of individual activity spaces. *Health & place*, 33, pp.195–202.

Heinrich, K.M. et al., 2007. Associations between the built environment and physical activity in public housing residents. *The international journal of behavioral nutrition and physical activity*, 4, p.56.

Hillsdon, M. et al., 2006. The relationship between access and quality of urban green space with population physical activity. *Public health*, 120(12), pp.1127–1132.

Hino, A.A.F. et al., 2011. The built environment and recreational physical activity among adults in Curitiba, Brazil. *Preventive Medicine*, 52(6), pp.419–422.

Hoehner, C.M. et al., 2005. Perceived and objective environmental measures and physical activity among urban adults. *Am J Prev Med*, 28(2), pp.105–116.

Huston, S. et al., 2003. Neighborhood Environment, Access to Places for Activity, and Leisure-time Physical Activity in a Diverse North Carolina Population. *American Journal of Health Promotion*, 18(1), pp.58–69.

IPEN, 2013. International Physical Activity and the Environment Network.

IPEN, 2016. International Physical Activity and the Environment Network. Available at: http://www.ipenproject.org/.

Ivory, V., Blakely, T., et al., 2015. Could strength of exposure to the residential neighbourhood modify associations between walkability and physical activity? *Social science & medicine (1982)*, 147, pp.232–41.

Ivory, V., Russell, M., et al., 2015. What shape is your neighbourhood? Investigating the micro geographies of physical activity. *Social Science and Medicine*, 133, pp.313–321.

Jones, A., Hillsdon, M. & Coombes, E., 2009. Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine*, 49(6), pp.500–505.

Jones, P., 2014. The evolution of urban mobility: The interplay of academic and policy perspectives. *IATSS Research*, 38(1), pp.7–13.

Kaczynski, A.T., 2010. Neighborhood Walkability Perceptions: Associations With Amount of Neighborhood-Based Physical Activity by Intensity and Purpose. *Journal of Physical Activity & Health*, 7(1), pp.3–10.

Kavanagh, A.M. et al., 2005. Urban area disadvantage and physical activity: a multilevel study in Melbourne, Australia. *Journal of epidemiology and community health*, 59(11), pp.934–40.

Kelly, C.E. et al., 2011. A comparison of three methods for assessing the walkability of the pedestrian environment. *Journal of Transport Geography*, 19(6), pp.1500–1508.

Kent, J., Thompson, S. & Jalaludin, B., 2011. *Healthy Built Environments, A review of the literature*, Sydney: City Futures Research Centre, UNSW.

Kerr, J. et al., 2013. Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. *Journal of physical activity & health*, 10(4), pp.581–601.

King, A.C. et al., 2011. Aging in neighborhoods differing in walkability and income: Associations with physical activity and obesity in older adults. *Social Science & Medicine*, 73(10), pp.1525–1533.

King, K.E. & Clarke, P.J., 2015. A Disadvantaged Advantage in Walkability: Findings From Socioeconomic and Geographical Analysis of National Built Environment Data in the United States. *American Journal of Epidemiology*, 181(1), pp.17–25.

Knuiman, M.W. et al., 2014. A Longitudinal Analysis of the Influence of the Neighborhood Built Environment on Walking for Transportation: The RESIDE Study. *American journal of epidemiology*, 180(5), pp.453–461.

Koohsari, M.J. et al., 2014. Street connectivity and walking for transport: Role of neighborhood destinations. *Preventive medicine*, 66, pp.118–22.

Krieger, N., 2012. Methods for the Scientific Study of Discrimination and Health: An Ecosocial Approach. *American Journal of Public Health*, 102(5), pp.936–945.

Kwan, M.-P., 2012. The Uncertain Geographic Context Problem. *Annals of the Association of American Geographers*, 102(5), pp.958–968.

Lake, A. & Townshend, T., 2006. Obesogenic environments: exploring the built and food environments. *Journal of the Royal Society for the Promotion of Health*, 126(6), pp.262–267.

Lamb, K.E. et al., 2012. Sociospatial distribution of access to facilities for moderate and vigorous intensity physical activity in Scotland by different modes of transport. *The international journal of behavioral nutrition and physical activity*, 9, p.55.

Lang, T. & Rayner, G., 2012. Ecological public health: the 21st century's big idea? An essay by Tim Lang and Geof Rayner. *BMJ*, 345, p.e5466.

Leadbetter, C., Geyer, J. & O´Connor, N., 2014. *The Scottish Health Survey. Physical Activity*,

Lee, C. & Moudon, A. V, 2004. Physical activity and environment research in the health field: Implications for urban and transportation planning practice and research. *Journal of Planning Literature*, 19(2), pp.147–181.

Lee, C. & Moudon, A.V., 2006. The 3Ds+R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment*, 11(3), pp.204–215.

Lee, I.M., Ewing, R. & Sesso, H.D., 2009. The Built Environment and Physical Activity Levels The Harvard Alumni Health Study. *American Journal of Preventive Medicine*, 37(4), pp.293–298.

Leslie, E. et al., 2005. Residents' perceptions of walkability attributes in objectively different neighbourhoods: a pilot study. *Health & Place*, 11(3), pp.227–236.

Lo, R.H., 2009. Walkability: what is it? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 2(2), pp.145–166.

Ma, L., 2014. The Objective vs. the Perceived Environment: What Matters for Active Travel. *Dissertations and Theses*, 2090.

Macdonald, L. et al., 2016. Walkability around primary schools and area deprivation across Scotland. *BMC Public Health*, 16(1), p.328.

Macintyre, S. et al., 1998. Do housing tenure and car access predict health because they are simply markers of income or self esteem? A Scottish study. *Journal of epidemiology and community health*, 52(10), pp.657–64.

Macintyre, S., Ellaway, A. & Cummins, S., 2002. Place effects on health: how can we conceptualise, operationalise and measure them? *Social Science & Medicine*, 55(1), pp.125–139.

Mackenbach, J.D. et al., 2016. Exploring why residents of socioeconomically deprived neighbourhoods have less favourable perceptions of their neighbourhood environment than residents of wealthy neighbourhoods. *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 17 Suppl 1, pp.42–52.

Maddison, R. et al., 2009. The environment and physical activity: The influence of psychosocial, perceived and built environmental factors. *International Journal of Behavioral Nutrition and Physical Activity*, 6.

Manaugh, K. & El-Geneidy, A., 2011. Validating walkability indices: How do different households respond to the walkability of their neighborhood? *Transportation Research Part D-Transport and Environment*, 16(4), pp.309–315.

Marmot, M., 2010. Fair Society Healthy Lives (The Marmot Review).

Marshall, W.E., Piatkowski, D.P. & Garrick, N.W., 2014. Community design, street networks, and public health. *Journal of Transport & Health*, 1(4), pp.1–15.

Martikainen, P., Bartley, M. & Lahelma, E., 2002. Psychosocial determinants of health in social epidemiology. *International Journal of Epidemiology*, 31(6), pp.1091–1093.

Mayne, D.J. et al., 2013. An objective index of walkability for research and planning in the Sydney Metropolitan Region of New South Wales, Australia: an ecological study. *International Journal of Health Geographics*, 12.

Mays, R.J. & Regensteiner, J.G., 2013. Exercise therapy for claudication: latest advances. *Current treatment options in cardiovascular medicine*, 15(2), pp.188–99.

McCormack, G.R. et al., 2012. The relationship between cluster-analysis derived walkability and local recreational and transportation walking among Canadian adults. *Health & Place*, 18(5), pp.1079–1087.

McCormack, G.R., Giles-Corti, B. & Bulsara, M., 2008. The relationship between destination proximity, destination mix and physical activity behaviors. *Prev Med*, 46, pp.33–40.

McCormack, G.R. & Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity*, 8.

McCulloch, A., Mohan, J. & Smith, P., 2012. Patterns of social capital, voluntary activity, and area deprivation in England. *Environment and Planning A*, 44(5), pp.1130–1147.

Mcilvenny, J., 2012. Intertidal areas. *Edina Share Geo*. Available at: http://www.sharegeo.ac.uk/.

McNeill, L.H., Kreuter, M.W. & Subramanian, S. V, 2006. Social environment and physical activity: a review of concepts and evidence. *Social science & medicine*, 63(4), pp.1011–1022.

Mehta, V., 2008. Walkable streets: pedestrian behavior, perceptions and attitudes. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 1(3), pp.217–245.

Merom, D. et al., 2003. An environmental intervention to promote walking and cycling—the impact of a newly constructed Rail Trail in Western Sydney. *Preventive Medicine*, 36(2), pp.235–242.

Millington, C. et al., 2009. Development of the Scottish Walkability Assessment Tool (SWAT). *Health & Place*, 15(2), pp.474–481.

Mitchell, R. & Popham, F., 2007. Greenspace, urbanity and health: relationships in England. *Journal of Epidemiology and Community Health*, 61(8), pp.681–683.

Mitchell, R.J. et al., 2015. Brief Report: Neighborhood Environments and Socioeconomic Inequalities in Mental Well-Being. *American Journal of Preventive Medicine*.

Moudon, A.V. et al., 1997. Effects of site design on pedestrian travel in mixed-use, medium-density environments. *Transportation Research Record: Journal of the Transportation Research Board*, 1578(1), pp.48–55.

Munro, D. et al., 2012. *An Evaluation of the Commonwealth Games 2014 Legacy for Scotland Report*,

Nagel, C.L. et al., 2008. The relation between neighborhood built environment and walking activity among older adults. *American Journal of Epidemiology*, 168(4), pp.461–468.

Nathan, A., Wood, L. & Giles-Corti, B., 2012. Examining objective and perceived distance to neighbourhood destinations and associations with walking for transport. *Journal of Aging and Physical Activity*, 20, pp.S225–S226.

National Records of Scotland, 2001. National Records of Scotland. Available at: http://www.gro-scotland.gov.uk/statistics/geography/2001-census-geographical-index.html) [Accessed January 1, 2015].

NICE, 2008. PH8 Physical activity and the environment: guidance.

NICE, 2006a. *Physical activity and the environment Review Two: Urban planning and design*, National Institute for Health and Care Excellence.

NICE, 2006b. *Physical activity and the environment Review One: Transport*, National Institute for Health and Care Excellence.

NICE, 2012. Walking and cycling: local measures to promote walking and cycling as forms of travel or recreation .

Norman, G.J. et al., 2006. Community design and acess to recreational facilities as correlates of adolescent physical activity and body-mass index. *Journal of Physical Activity and Health*, 3(118–128), pp.3–7.

Oakes, J.M., Forsyth, A. & Schmitz, K.H., 2007. The effects of neighborhood density and street connectivity on walking behavior: the Twin Cities walking study. *Epidemiologic perspectives & innovations : EP+I*, 4(1), p.16.

Ogilvie, D. et al., 2008. Personal and environmental correlates of active travel and physical activity in a deprived urban population. *International Journal of Behavioral Nutrition and Physical Activity*, 5.

Ogilvie, D. et al., 2011. Recreational physical activity facilities within walking and cycling distance: Sociospatial patterning of access in Scotland. *Health & Place*, 17(5), pp.1015–1022.

Oluyomi, A.O. et al., 2014. Physical Activity Guideline in Mexican-Americans: Does the Built Environment Play a Role? *Journal of Immigrant and Minority Health*, 16(2), pp.244–255.

Ord, K., Mitchell, R. & Pearce, J., 2013. Is level of neighbourhood green space associated with physical activity in green space? *The International Journal of Behavioral Nutrition and Physical Activity*, 10(1), p.127.

Ordnance Survey, 2016a. Meridan 2 layer.

Ordnance Survey, 2016b. Points of Interest data. Available at: https://www.ordnancesurvey.co.uk/business-and-government/products/points-of-interest.html.

OS, 2013. OS MasterMap ITN Layer.

Owen, N. et al., 2007. Neighborhood walkability and the walking behavior of Australian adults. *Am J Prev Med*, 33(5), pp.387–395.

Owen, N. et al., 2004. Understanding environmental influences on walking: review and research agenda. *Am J Prev Med*, 27(1), pp.67–76.

Pak, B. & Verbeke, J., 2013. Walkability as a Performance Indicator for Urban Spaces. *Crowdsourcing and Sensing*, 1, pp.423–432.

Pan, S. et al., 2009. Individual, social, environmental, and physical environmental correlates with physical activity among Canadians: a cross-sectional study. *BMC Public Health*, 9(1), p.21.

Panter, J.R. & Jones, A., 2010. Attitudes and the Environment as Determinants of Active Travel in Adults: What Do and Don't We Know? *Journal of Physical Activity & Health*, 7(4), pp.551–561.

Papas, M.A. et al., 2007. The built environment and obesity. *Epidemiologic Reviews*, 29, pp.129–143.

Pearce, J. et al., 2007. Are socially disadvantaged neighbourhoods deprived of health-related community resources? *International Journal of Epidemiology*, 36(2), pp.348–355.

Pearce, J. & Maddison, R., 2011. Do enhancements to the urban built environment iprove physical activity levels among socially disadvantaged populations? *International Journal for Equity in Health*, 10(28).

Pearce, J.R. et al., 2010. Environmental justice and health: the implications of the socio-spatial distribution of multiple environmental deprivation for health inequalities in the United Kingdom. *Transactions of the Institute of British Geographers*, 35(4), pp.522–539.

Perchoux, C. et al., 2016. Residential buffer, perceived neighborhood, and individual activity space: New refinements in the definition of exposure areas – The RECORD Cohort Study. *Health & Place*, 40, pp.116–122.

Petticrew, M. et al., 2004. Evidence for public health policy on inequalities: 1: the reality according to policymakers. *Journal of epidemiology and community health*, 58(10), pp.811–6.

Physical Activity Task Force, 2003. *Let's make Scotland more active*, Edinburgh.

Pikora, T. et al., 2003. Developing a framework for assessment of the environmental determinants of walking and cycling. *Social Science & Medicine*, 56(8), pp.1693–1703.

Pikora, T.J. et al., 2006. Neighborhood environmental factors correlated with walking near home: Using SPACES. *Medicine and Science in Sports and Exercise*, 38(4), pp.708–714.

Pliakas, T., Wilkinson, P. & Tonne, C., 2014. Contribution of the physical environment to socioeconomic gradients in walking in the Whitehall II study. *Health & place*, 27, pp.186–93.

Pooley, C. et al., 2011. *Understanding Walking and Cycling*, Lancaster.

Powell, L.M. et al., 2006. Availability of physical activity-related facilities and neighborhood demographic and socioeconomic characteristics: a national study. *American journal of public health*, 96(9), pp.1676–80.

Pratt, M. et al., 2015. Does Perceived Neighborhood Walkability and Safety Mediate the Association Between Education and Meeting Physical Activity Guidelines? *Preventing Chronic Disease*, 12, p.E46.

Reid, S., 2008. Fit for purpose: evaluating walkability. *Proceedings of the Institution of Civil Engineers-Engineering Sustainability*, 161(2), pp.105–112.

Reis, S. et al., 2013. Walkability and physical activity: findings from Curitiba, Brazil. *American journal of preventive medicine*, 45(3), pp.269–275.

Rhodes, R.E. & Nigg, C.R., 2011. Advancing physical activity theory: a review and future directions. *Exercise and sport sciences reviews*, 39(29), pp.113–119.

Rind, E., Jones, A. & Southall, H., 2014. How is post-industrial decline associated with the geography of physical activity? *Social Science & Medicine*, 104, pp.88–97.

Riva, M. et al., 2009. Disentangling the relative influence of built and socioeconomic environments on walking: The contribution of areas homogenous along exposures of interest. *Social Science & Medicine*, 69(9), pp.1296–1305.

Robert Wood Johnson Foundation, 2011. The Power of Trails for Promoting Physical Activity in Communities - Research Brief. , (January), p.8.

Rodríguez, D.A. et al., 2008. Relation of modifiable neighborhood attributes to walking. *Preventive medicine*, 47(3), pp.260–4.

Rundle, A.G. et al., 2015. Using GPS Data to Study Neighborhood Walkability and Physical Activity. *American journal of preventive medicine*, 50(3), pp.e65-72.

Saelens, B.E. & Handy, S.L., 2008. Built environment correlates of walking: a review. *Med Sci Sports Exerc*, 40, pp.S550-566.

Saelens, B.E., Sallis, J.F. & Frank, L.D., 2003. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25(2), pp.80–91.

Sallis, J.E. et al., 2006. An ecological approach to creating active living communities. *Annual Review of Public Health*, 27, pp.297–322.

Sallis, J.F. et al., 2004. Active transportation and physical activity: opportunities for collaboration on transportation and public opportunities health research. *Transportation Research Part a-Policy and Practice*, 38(4), pp.249–268.

Sallis, J.F., Owen, N. & Fisher, E.B., 2008. Ecological models of health behavior. In K. Glanz, B. K. Rimer, & K. Viswanath, eds. *In Health behavior and health education: theory, research and practice*. San Francisco: Jossey-Bass, pp. 465–485.

Salvo, D. et al., 2014. Characteristics of the Built Environment in Relation to Objectively Measured Physical Activity Among Mexican Adults, 2011. *Preventing Chronic Disease*, 11.

ScotStat, 2012. Scottish Government Statistics. , 2013.

Scottish Executive, 2001. *The Role of the Planning System in the Provision*, Seaman, P.J., Jones, R. & Ellaway, A., 2010. It's not just about the park, it's about integration too: why people choose to use or not use urban greenspaces. *The international journal of behavioral nutrition and physical activity*, 7(1), p.78.

Shortt, N.K. et al., 2014. Integrating environmental justice and socioecological models of health to understand population-level physical activity. *Environment and Planning A*, 46(6), pp.1479–1495.

SIMD, 2009. SIMD 2009 Technical Report. *Scottish Index of Multiple Deprivation 2009*.

Siu, V.W. et al., 2012. Built environment and its influences on walking among older women: Use of standardized geographic units to define urban forms. *Journal of Environmental and Public Health*, 2012.

Smart Growth America, 2016. What is "smart growth?" | Smart Growth America. Available at: http://www.smartgrowthamerica.org/what-is-smart-growth [Accessed April 1, 2016].

Spence, J.C. & Lee, R.E., 2003. Toward a comprehensive model of physical activity. *Psychology of Sport and Exercise*, 4(1), pp.7–24.

Stafford, M. et al., 2007. Pathways to obesity: Identifying local, modifiable determinants of physical activity and diet. *Social Science & Medicine*, 65(9), pp.1882–1897.

Stokols, D., 1996. Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion*, 10(4), pp.282–298.

Sugiyama, T. et al., 2014. Perceived neighbourhood environmental attributes associated with adults′ recreational walking: IPEN Adult study in 12 countries. *Health & Place*, 28(0), pp.22–30.

Sugiyama, T. et al., 2009. Physical activity for recreation or exercise on neighbourhood streets: Associations with perceived environmental attributes. *Health and Place*, 15(4), pp.1058–1063.

Sugiyama, T., Neuhaus, M. & Owen, N., 2012. Active Transport, the Built Environment, and Human Health. In S. T. Rassia & P. M. Pardalos, eds. *Sustainable Environmental Design in Architecture Impacts on Health*. Springer Optimization and its Applications. London: Springer, pp. 43–65.

Sundquist, K. et al., 2011. Neighborhood walkability, physical activity, and walking behavior: The Swedish Neighborhood and Physical Activity (SNAP) study. *Social Science & Medicine*, 72(8), pp.1266–1273.

Taylor, W. et al., 2006. Environmental Justice: Obesity, Physical Activity, and Healthy Eating . *Journal of Physical Activity and Health*, Suppl 1, pp.S30–S54.

The Scottish Government, 2003a. A World of opportunity - A Guide to Education and Training in Scotland.

The Scottish Government, 2013a. *Creating Places A policy statement on architecture and place for Scotland*,

The Scottish Government, 2010a. *Designing Streets - A policy statement for Scotland*,

The Scottish Government, 2008. *Equally Well: Report of the ministerial task force on health inequalities*, Edinburgh.

The Scottish Government, 2014. *Let's Get Scotland Walking The National Walking*

Strategy,

The Scottish Government, 2010b. *National Statistics - The Scottish Health Survey 2010 Volume 2: Technical Report*,

The Scottish Government, 2013b. *Placemaking*, Edinburgh: Scottish Government, St. Andrew's House, Regent Road, Edinburgh.

The Scottish Government, 2010c. *Scottish Government Urban/Rural Classification 2009-2010*,

The Scottish Government, 2011. Scottish Index of Multiple Deprivation.

The Scottish Government, 2012. *Scottish Index of Multiple Deprivation 2012: A National Statistics Publication for Scotland*,

The Scottish Government, 2009. SNS Lookup - Output Area - SNSCOA04BP.

The Scottish Government, 2003b. The Scottish Crime Survey. Available at: http://www.gov.scot/Publications/2004/12/20379/48111.

Thielman, J. et al., 2015. Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive medicine*, 77, pp.174–180.

Thornton, L.E., Pearce, J.R. & Kavanagh, A.M., 2011. Using Geographic Information Systems (GIS) to assess the role of the built environment in influencing obesity: a glossary. *The international journal of behavioral nutrition and physical activity*, 8(1), p.71.

Townshend, T. & Lake, A.A., 2009. Obesogenic urban form: theory, policy and practice. *Health & place*, 15(4), pp.909–916.

Transport Scotland, 2005. Scotland Today. *Scotland Planning Assessment Part 2*. Available at: http://www.transportscotland.gov.uk/report/j7106v1-03.htm [Accessed November 12, 2015].

TRB, 2005. *Does the Built Environment Influence Physical Activity? Examining the Evidence TRB special report 282*, Transport Research Board.

Troped, P.J. et al., 2003. Correlates of recreational and transportation physical activity among adults in a New England community. *Preventive Medicine*, 37(4), pp.304–310.

Troped, P.J. et al., 2010. The Built Environment and Location-Based Physical Activity. *American Journal of Preventive Medicine*, 38(4), pp.429–438.

Turrell, G. et al., 2013. Can the built environment reduce health inequalities? A study of neighbourhood socioeconomic disadvantage and walking for transport. *Health & Place*, 19, pp.89–98.

UK Data Service Census Support, M., 2013. Casweb.

Vargo, J., Stone, B. & Glanz, K., 2012. Google walkability: a new tool for local planning and public health research? *J Phys Act Health*, 9(5), pp.689–697.

Villanueva, K. et al., 2014. The impact of neighborhood walkability on walking: Does it differ across adult life stage and does neighborhood buffer size matter? *Health & Place*, 25, pp.43–46.

Weiner, E., 1992. *Urban Transportation Planning In The US - A Historical Overview*, Washington DC.

Wells, N. & Yang, Y., 2008. Neighborhood design and walking. A quasi-experimental longitudinal study. *Am J Prev Med*, 34, pp.313–319.

Wheeler, B.W. et al., 2015. Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. *International journal of health geographics*, 14(1), p.17.

Whitehead, C., 2008. The Density Debate: A Personal View. , p.21.

WHO, 2010a. A Conceptual Framework for Action on the Social Determinants of Health.

WHO, 2003. Gender, Health and Ageing.

WHO, 2010b. *Global recommendations on physical activity for health*, http://www.who.int/dietphysicalactivity/factsheet_adults/en/.

WHO, 2012. *Health Indicators of sustainable cities in the Context of the Rio + 20 UN Conference on Sustainable Development Key messages*,

Witten, K. et al., 2012. Neighborhood Built Environment and Transport and Leisure Physical Activity: Findings Using Objective Exposure and Outcome Measures in New Zealand. *Environmental Health Perspectives*, 120(7), pp.971–977.

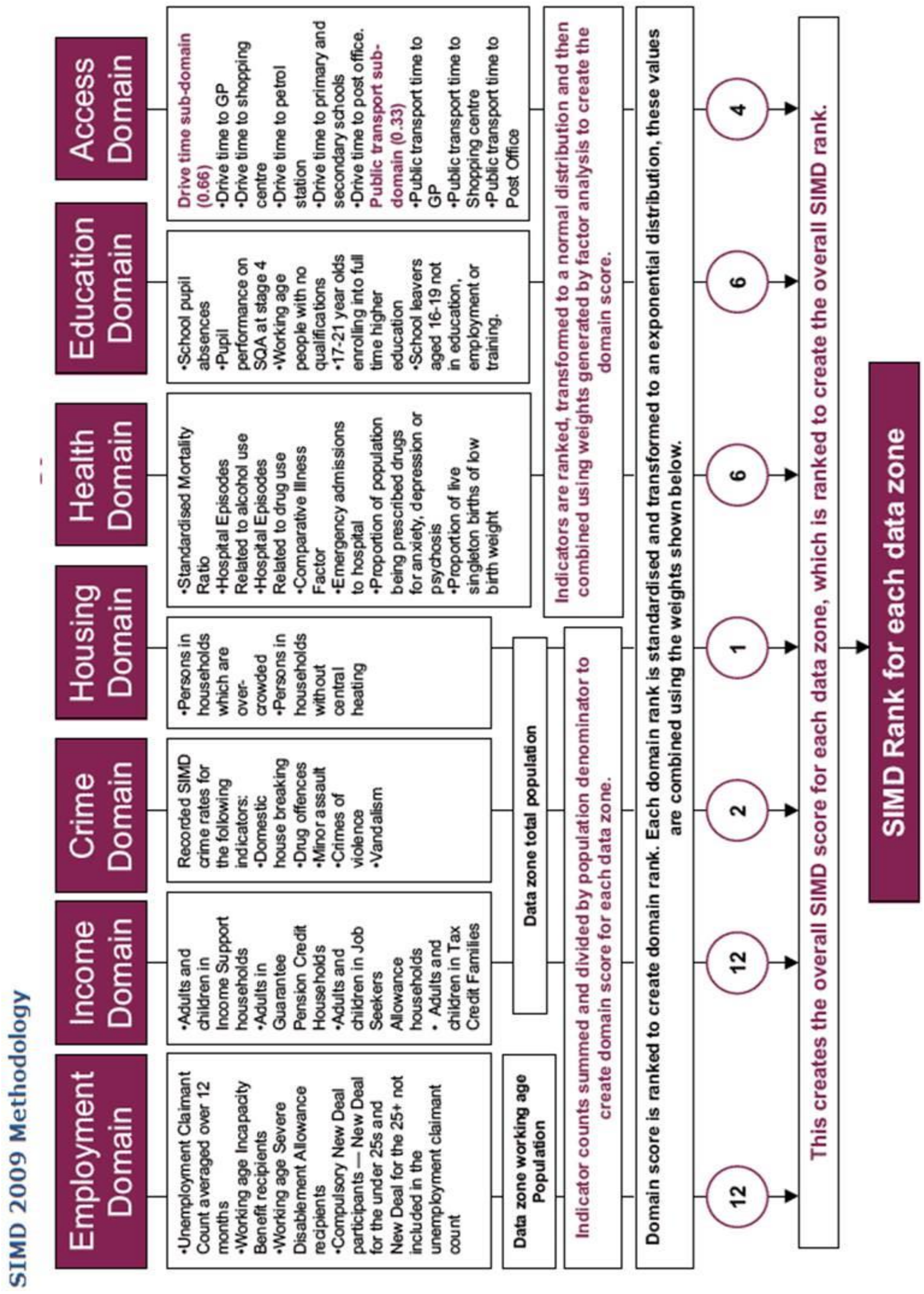
Witten, K., Pearce, J. & Day, P., 2011. Neighbourhood Destination Accessibility Index: a GIS tool for measuring infrastructure support for neighbourhood physical activity. *Environment and Planning A*, 43(1), pp.205–223.

Appendix A: Domains, subcategories and classes used to create the destination accessibility score

Domain	Subcategories	Classes
Health	Chemists	Chemists and pharmacies
	Doctors surgeries	Clinics and health centres; doctor's surgeries
Public transit	public transport stations/stops	Bus stops; hail and ride zones; tram, metro and light railway stations and stops; underground network stations
Education	secondary school	Broad age range and secondary state schools
	primary schools	Independent and preparatory schools, first, primary and infant schools
	Pre-school, afterschool	Nursery schools and pre and after school care
Open space	accessible open space	Woodland, open semi-natural, playspace, general amenity, public parks/gardens, beaches
Social and cultural	sports complexes, outdoor pursuits	Athletics facilities; bowling facilities; climbing facilities; golf ranges, course, clubs and professionals; ice rinks; Gymnasiums, sports halls and leisure facilities; snooker and pool halls; squash courts; swimming pools; tennis facilities; riding schools, livery stables and equestrian centres; allotments
	Alcohol outlets	Pubs, bars and inns,
	Eating and drinking	Restaurants; cafes, snack bars and tea rooms; fast food and takeaway outlets; fish and chip shops,
	Community centres	Halls and community centres
	Libraries	Libraries
	Venues, stage and screen:	Cinemas; discos; nightclubs; social clubs; theatres and concert halls
	Worship	Places of worship
	Attractions (museums, art galleries, historical, zoological and botanical)	Aquaria and sea life centres; bird reserves, collections and sanctuaries, butterfly farms; farm-based attractions; horticultural attractions; zoos and animal collections; Archaeological sites; art galleries; historic and ceremonial structures; historic buildings including castles, forts and abbeys; historical ships; museums
Non-food retail	Clothing, accessories, household, office, leisure and garden	**Clothing and accessories:** baby and nursery equipment and children's clothes; clothing; footwear; jewellery and fashion accessories; lingerie and hosiery) **Household, office**, **leisure and garden:** art and antiques; books and maps; camping and caravanning; carpets, rugs, soft furnishings and needlecraft; charity shops; china and glassware; computer supplies; cosmetics, toiletries, perfumes and hairdressing supplies; craft supplies; cycles and accessories; department stores; discount stores; diy and home improvement; domestic appliances; electrical goods and components; florists; furniture; fuel distributors and suppliers; garages, garden and portable buildings; garden centres and nurseries; garden machinery and furniture; general household goods; gifts and cards; hobby, sports and pastime products; leather goods, luggage and travel accessories; lighting; mail order and catalogue stores; music and video; musical instruments; party goods and novelties; pets, supplies and services; photographic and optical equipment; second-hand goods; stationary and office supplies; surplus goods; telephones and telephone cards; travel agencies)
Financial	Cash machines cash points	Cash machines cash points
	post offices	Post offices
Food retail	Supermarkets, frozen foods	Supermarkets; frozen foods
	- newsagents and tobacconists - convenience and general - alcoholic drinks	Newsagents and tobacconists; alcoholic drinks
	specialist, markets	Herbs and spices; organic; health and kosher; tea and coffee; bakeries, butchers & fishmongers; confectioners; delicatessen, green and new age goods; grocers, farm shops and pick your own
	convenience and general	Convenience and general

Employment	Commercial	Construction services consultancies; employment and career agencies; engineering services; contract services; IT, advertising, marketing and media services; legal and financial (not cash machines, not paypoint locations); personal, consumer and other services; property and development services; recycling services (not the same as domestic recycling drop off); repair and servicing; research and design; transport, storage and delivery; hire services
	industrial	Consumer products; extractive industries food stuffs; industrial products; farming
	Institutional	Higher education establishments; armed services; central government; coastal safety; consular services; courts; driving tests centres; embassies and consulates; fire brigade stations; job centres; local government; members of parliament; police stations; prisons; probation and police support; registrars; revenue and customs; social services; Animal welfare organisations; charitable organisations; community networks and projects; fan clubs and associations; institutes and professional organisations; political parties; religious organisations; sports clubs and associations; youth organisations

Appendix B: 2009 Scottish Index of Multiple Deprivation (SIMD) Methodology



Source (SIMD 2009)

Appendix C: Full list of questions about adults' walking in the 2010 Scottish Health Survey

- Walked continuously for at least 5 minutes in last 4 weeks (indiv)
- Walked continuously for at least 10 mins in last 4 weeks indiv)
- How many days of 10 minute walks in last 4 weeks (indiv)
- Whether did more than one 10 minute walk per day (indiv)
- How many days did more than one 10 minute walk per day indiv
- Walking hours (indiv)
- Walking minutes (indiv)
- HrsWlk + MinWlk in minutes (indiv)
- Speed of usual walking pace (indiv)
- Days 10+min brisk walk (Derived)
- Days 10+min brisk walk (grouped) Derived)
- Walking - any or none (10 min) (Derived)
- Number of walks of 10 mins+ in last 4 weeks (Derived)
- Average hours walking per week brisk or fast (10 min) Derived)
- Average hours walking per week brisk or fast (grouped) (10 min) Derived)
- Number of days walking 30 mins + fast or brisk, including 10-29 min bouts (Derived)

(indiv) indicates that questions were directly asked of individuals
(Derived) indicates that the variable was derived using the direct questions
Source: (SHeS, 2010)